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FIXED-BASE SIMULATOR INVESTIGATION OF THE EFFECTS OF L_α AND TRUE SPEED ON PILOT OPINION OF LONGITUDINAL FLYING QUALITIES

TECHNICAL DOCUMENTARY REPORT ASD-TDR-63-399

NOVEMBER 1963

Flight Dynamics Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Project No. 8219, Task No. 821905

(Prepared under Contract No. AF 33(657)-7442 by the Cornell Aeronautical Laboratory, Inc., Buffalo, New York Author: Charles R. Chalk)

FOREWORD

This report was prepared for the United States Air Force by the Cornell Aeronautical Laboratory, Inc., Buffalo, New York in partial fulfillment of Contract AF33(657)-7442; Exhibit "B", Item VII.

The program was performed by the Flight Research Department of the Cornell Aeronautical Laboratory, Inc. under the sponsorship of the Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, United States Air Force, Wright-Patterson Air Force Base, Ohio as Task 821905 of Project 8219. Mr. R. Wasicko was project engineer for the Air Force Flight Dynamics Laboratory.

ABSTRACT

The effects of L_α and true speed on longitudinal flying qualities, optimum control gain, and normal acceleration response to turbulence were investigated in a ground simulator. The steady state ratio of normal acceleration to angle of attack was found to be of significance both to the flying qualities of an airplane and to the optimum longitudinal control gain. Normal acceleration response to rough air was demonstrated to be primarily a function of L_α and the short period frequency and damping ratio.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

Charles B. Westbrook
Charles B. Westbrook
Chief Control Criteria Branch
Flight Control Division

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SYMBOLS AND DEFINITIONS

The basic symbols used in this report are defined below. In a few cases symbols are used which relate only to the immediate text in which they appear. These are defined when they are introduced.

Dimensional Units

Distance - feet

Time - seconds

Angle - radians (unless otherwise stated)

Force - pounds

Moment - foot-pounds

Mass - slugs

Aerodynamic Notation

a_z	component of acceleration of airplane cg along Z stability axis
b	wing span
c	wing chord
C_ℓ	rolling moment coefficient, $L/q_o Sb$
C_m	pitching moment coefficient, $M/q_o Sc$
C_n	yawing moment coefficient, $N/q_o Sb$
C_D	drag coefficient, $D/q_o S$
C_L	lift coefficient, $L/q_o S$
C_Y	side force coefficient, $Y/q_o S$
D	drag, force in plane of symmetry and parallel to component of relative wind in plane of symmetry, positive aft
F_s	stick force
g	acceleration of gravity (i. e., 32. 2 ft/sec^2)
h	altitude
$I_{xx}, I_{yy}, I_{zz}, I_{xz}$	airplane moments and products of inertia about body axes

<u>Aerodynamic Notation (continued)</u>

L	lift, force in plane of symmetry and normal to component of relative wind in the plane of symmetry, positive up
L	rolling moment about X body axis, positive right wing down
M	pitching moment about Y body axis, positive nose up
N	yawing moment about Z body axis, positive nose right
m	mass
n_z	normal accelerometer reading in g units, positive in pull-up
p, q, r	angular velocities about X, Y, Z body axes respectively
P_{S_x}	thrust force along X stability axis
q_c	dynamic pressure, $= \frac{1}{2}\rho V^2$
S	wing area
u, v, w	incremental velocity along the X, Y, Z reference axes respectively
V	airspeed
w_{ag}	vertical gust velocity, positive up
W	weight
X_s	aerodynamic force along X stability axis, positive forward
Y_s	aerodynamic force along Y stability axis, positive to right
Z_s	aerodynamic force along Z stability axis, positive down
α	angle of attack
β	angle of sideslip
γ	flight path angle, positive up
δ_a	aileron angle, positive right aileron down
δ_{AS}	aileron stick deflection, positive right
δ_E	elevator angle, positive trailing edge down
δ_{ES}	elevator stick deflection, positive back

Aerodynamic Notation (continued)

δ_r	rudder angle, positive trailing edge left
δ_{RP}	rudder pedal deflection, positive right pedal forward
Θ	attitude angle, angle between X body axis and the horizontal plane
ρ	air density
ϕ	bank angle, angle between Y body axis and a horizontal line in the Y-Z plane
ψ	heading angle, angle between reference azimuth (North) and the projection of the X body axis in the horizontal plane

The following expressions were used in the analog mechanization of the drag and lift equations:

$$C_D = C_{D_0} + C_{D_\alpha}\alpha + C_{D_{\alpha^2}}\alpha^2$$

$$C_L = C_{L_0} + C_{L_\alpha}\alpha$$

C_{D_0} ~ drag coefficient at $\alpha = 0$

C_{D_α} ~ drag coefficient proportional to α , 1/deg

$C_{D_{\alpha^2}}$ ~ drag coefficient proportional to α^2 , 1/deg^2

C_{L_0} ~ lift coefficient at $\alpha = 0$

C_{L_α} ~ lift coefficient proportional to α , 1/deg

The following stability derivative notation is used:

$$C_{D_\alpha} = \frac{\partial C_D}{\partial \alpha} \qquad C_{L_\alpha} = \frac{\partial C_L}{\partial \alpha} \qquad C_{n_p} = \frac{2V}{b}\frac{\partial C_n}{\partial p}$$

$$C_{\ell_p} = \frac{2V}{b}\frac{\partial C_\ell}{\partial p} \qquad C_{L_{\delta_e}} = \frac{\partial C_L}{\partial \delta_e} \qquad C_{n_r} = \frac{2V}{b}\frac{\partial C_n}{\partial r}$$

$$C_{\ell_r} = \frac{2V}{b}\frac{\partial C_\ell}{\partial r} \qquad C_{m_q} = \frac{2V}{c}\frac{\partial C_m}{\partial q} \qquad C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$$

$$C_{\ell_\beta} = \frac{\partial C_\ell}{\partial \beta} \qquad C_{m_\alpha} = \frac{\partial C_m}{\partial \alpha} \qquad C_{n_{\delta_a}} = \frac{\partial C_n}{\partial \delta_a}$$

$$C_{\ell_{\delta_a}} = \frac{\partial C_\ell}{\partial \delta_a} \qquad C_{m_{\dot\alpha}} = \frac{2V}{c}\frac{\partial C_m}{\partial \dot\alpha} \qquad C_{n_{\delta_r}} = \frac{\partial C_n}{\partial \delta_r}$$

$$C_{\ell_{\delta_r}} = \frac{\partial C_\ell}{\partial \delta_r} \qquad C_{m_{\delta_e}} = \frac{\partial C_m}{\partial \delta_e} \qquad C_{Y_\beta} = \frac{\partial C_Y}{\partial \beta}$$

$$C_{Y_{\delta_r}} = \frac{\partial C_Y}{\partial \delta_r}$$

The following dimensional stability derivative notation is used:

$$L_\alpha = \frac{\rho S V}{2m} C_{L_\alpha} \qquad X_u = -\frac{\rho S V}{m}\left(C_D + C_{D_u}\right)$$

$$L_\delta = \frac{\rho S V}{2m} C_{L_\delta} \qquad X_w = \frac{\rho S V}{2m}\left(C_L - C_{D_\alpha}\right)$$

$$M_q = \frac{q_0 S c}{I_{yy}} \frac{c}{2V} C_{m_q} \qquad Z_u = -\frac{\rho S V}{m}\left(C_L + C_{L_u}\right)$$

$$M_\alpha = \frac{q_0 S c}{I_{yy}} C_{m_\alpha} \qquad Z_w = -\frac{\rho S V}{2m}\left(C_{L_\alpha} + C_D\right)$$

$$M_{\dot\alpha} = \frac{q_0 S c}{I_{yy}} \frac{c}{2V} C_{m_{\dot\alpha}} \qquad Z_\delta = -\frac{\rho S V^2}{2m} C_{L_{\delta_e}}$$

$$M_\delta = \frac{q_0 S c}{I_{yy}} C_{m_{\delta_e}}$$

Transfer Function Notation

f_n	undamped natural frequency, cycles/second
K	gain factor
s	Laplace operator
ζ	damping ratio
τ	time constant
ω	frequency, radians/second
ω_n	undamped natural frequency, radians/second
$G(j\omega)$	transfer function of filter
$Y(j\omega)$	transfer function of airplane
$\phi(\omega)$	power spectral density

Axes

The following axes are right-hand orthogonal sets with origin at the center of gravity.

Stability Axes

X	in the plane of symmetry, directed along the projection of the wind vector in that plane
Y	normal to the plane of symmetry, directed along the right wing
Z	in the plane of symmetry, directed "down"

These axes rotate with respect to the airplane, but only in the plane of symmetry.

Body Axes

X	in the plane of symmetry, directed toward the nose of the airplane - coincides with the X stability axis in reference condition
Y	normal to the plane of symmetry, directed along the right wing
Z	in the plane of symmetry, directed "down"

The body axes, as used in this report, are oriented so as to coincide with stability axes in trimmed level flight at the reference speed. These axes are fixed in the airplane.

SECTION 1

INTRODUCTION

1.1 BACKGROUND

Under the sponsorship of the Research and Technology Division of the Air Force Systems Command, a comprehensive handling quality research program has been undertaken by several organizations. The objective of this program is to develop and validate a fundamental and generalized technique for establishing suitable handling quality requirements and design criteria for future piloted vehicles.

As a part of this program, the Flight Research Department of the Cornell Aeronautical Laboratory, Inc., Buffalo, New York is conducting a continuing experimental research program to obtain valid handling quality data under realistic ground and flight simulation environments. The objective of this program is to establish and validate definitive individual parameter effects as a basis towards complete handling quality understanding, and to establish interaction influences which are fundamentally required for generalized knowledge of the handling quality problem. The program utilizes the three-axis variable stability T-33 airplane for the ground and flight simulation experiments. For the program described in this report the T-33 airplane was used as a fixed-base simulator.

1.2 PURPOSE

In the past, considerable empirical handling quality research has been focused on the aircraft's natural modes of motion, which are defined by the characteristic equation or transfer function denominators. Although the characteristic equation alone defines the frequency and damping ratio or the time constants of the natural modes of motion, the numerator terms of the airplane transfer functions contribute to the relative amplitude and phase of the various airplane responses.

The current study was directed toward investigating the effects on pilot rating of large variations in the relative amplitude and phase of the basic airplane responses to elevator control. These variations were obtained through changes in true speed and the parameter $L_\alpha = \frac{\rho S V}{2m} C_{L_\alpha}$.* Information was also obtained on the factors which determine the optimum airframe longitudinal sensitivity to pilot control.

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* Note that as used in this report, L_α can be considered to be the derivative of lift-induced acceleration with respect to the velocity component along the Z stability axis, (L_α is approximately equal to $-Z_w$ of References 9, 10, and 12).

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1.3 APPROACH

This experiment was designed from the outset to use pilot ratings rather than task performance as a measure of the acceptability of a particular configuration. The weakness of task performance measures in airplane handling qualities work is the difficulty in choosing tasks and response parameters to measure which can be shown to give a valid measure of the over-all acceptability of a particular pilot-vehicle combination. Another difficulty arises from the ability of the pilot to compensate for the deficiencies in the handling qualities, making the task performance measurements relatively insensitive to changes in the handling qualities. The latter effect, which had been noticed in some previous handling qualities studies such as References 7 and 8, has recently received some clarification from studies of the representation of a human controller from a servomechanism viewpoint. Reference 10, for example, sets up a servo model of the human which fits experimental data, and then shows how the human alters his characteristics to fit the dynamics of the device he is operating, and how his opinion of the goodness of the device can be related to the amount that he has to alter his characteristics to maintain his task performance. This promising line of attack has not yet progressed to the point where we can dispense with experimental determination, in a realistic situation, of the suitability of various handling qualities as determined by pilot ratings. The complexity of the interrelation between handling qualities requires a high degree of realism in the tests to compensate for the inability of the experimenter to control all the necessary variables, or sometimes to know all the variables which are, in fact, affecting the pilot. The variable stability airplane is particularly well suited to this kind of testing because it provides a high degree of realism with convenient control over many of the important variables. Thus, the method by which these evaluations were made was a series of experiments in which pilots were put in control of a vehicle whose dynamic characteristics were alterable. The vehicle characteristics to be studied were simulated on an analog computer with the responses displayed on the T-33 instrument display. The pilot controlled the simulated vehicle through the T-33 control system and performed a series of maneuvers representative of those maneuvers which might be called for under instrument flight conditions. His comments regarding his control difficulties, his objections to the dynamic flight characteristics of the vehicle, his selection of optimum elevator control system gain, and his subjective evaluation of the suitability of the vehicle's characteristics for instrument flight form the bulk of the data.

1.4 ARRANGEMENT OF REPORT

Section 2 of this report discusses the theoretical basis of the investigation and poses the questions to be answered by the experiment.

Section 3 of the report describes the design of the experiment and the general arrangement of the simulator. Specific details of the simulation equipment are contained in Appendix A. The subjects in the experiment, the maneuvers performed, the frame of reference within which the evaluations were made, and the rating scale used are described in the remainder of Section 3 and in Appendix B.

The program results are presented and discussed in detail in Section 4. Results and conclusions are summarized in Section 5.

For convenience Appendix C lists the simplified longitudinal equations of motion (short period approximation) and the pertinent transfer functions used in the discussions throughout this report.

For completeness, Appendix D lists the values of phugoid frequency and damping ratio together with several three-degree-of-freedom transfer function numerator time constants which existed for the various configurations in level flight. Appendix D also includes tabulated data pertinent to the experiment.

Appendix E contains a sampling of the verbatim pilot comments obtained during the program.

SECTION 2

THEORETICAL BASIS

2.1 RELATIVE AMPLITUDE AND PHASE OF RESPONSES TO ELEVATOR CONTROL

The major effects of the magnitude of the parameter L_{α} and the true speed V are to change the relative amplitude and phase of the airplane responses.

This can be seen by examining the transfer functions derived in Appendix C and the time histories of airplane responses to an elevator step input illustrated in Figures 1 and 2. (Also Figures 14a, 14b, 14c)

The transfer function expressions C-24 through C-28 indicate the functional relations between the magnitude and phase of various response variables when the airplane is disturbed through the elevator.

Using approximate expressions:

$$\frac{n_z(s)}{\dot{\theta}(s)} \cong \frac{V}{g} \frac{1}{\left(\frac{1}{L_{\alpha}} s + 1\right)} \qquad \text{(C-24)}$$

$$\frac{\dot{\gamma}(s)}{\dot{\theta}(s)} = \frac{1}{\left(\frac{1}{L_{\alpha}} s + 1\right)} \qquad \text{(C-25)}$$

$$\frac{\alpha(s)}{\dot{\theta}(s)} \cong \frac{1}{L_{\alpha}} \frac{1}{\left(\frac{1}{L_{\alpha}} s + 1\right)} \qquad \text{(C-26)}$$

$$\frac{\dot{\gamma}(s)}{\alpha(s)} \cong L_{\alpha} \qquad \text{(C-27)}$$

$$\frac{n_z(s)}{\alpha(s)} \cong \frac{V}{g} L_{\alpha} \qquad \text{(C-28)}$$

The normal acceleration, angle of attack, and rate of change of flight path angle all lag the pitch rate or conversely the pitch rate leads these responses with a time constant that is equal to $1/L_{\alpha}$. The steady state normal acceleration is related to steady state pitch rate by V/g and to angle of attack by $\frac{V}{g} L_{\alpha}$. The steady state pitch rate and rate of change of flight path angle are related to angle of attack by L_{α}.

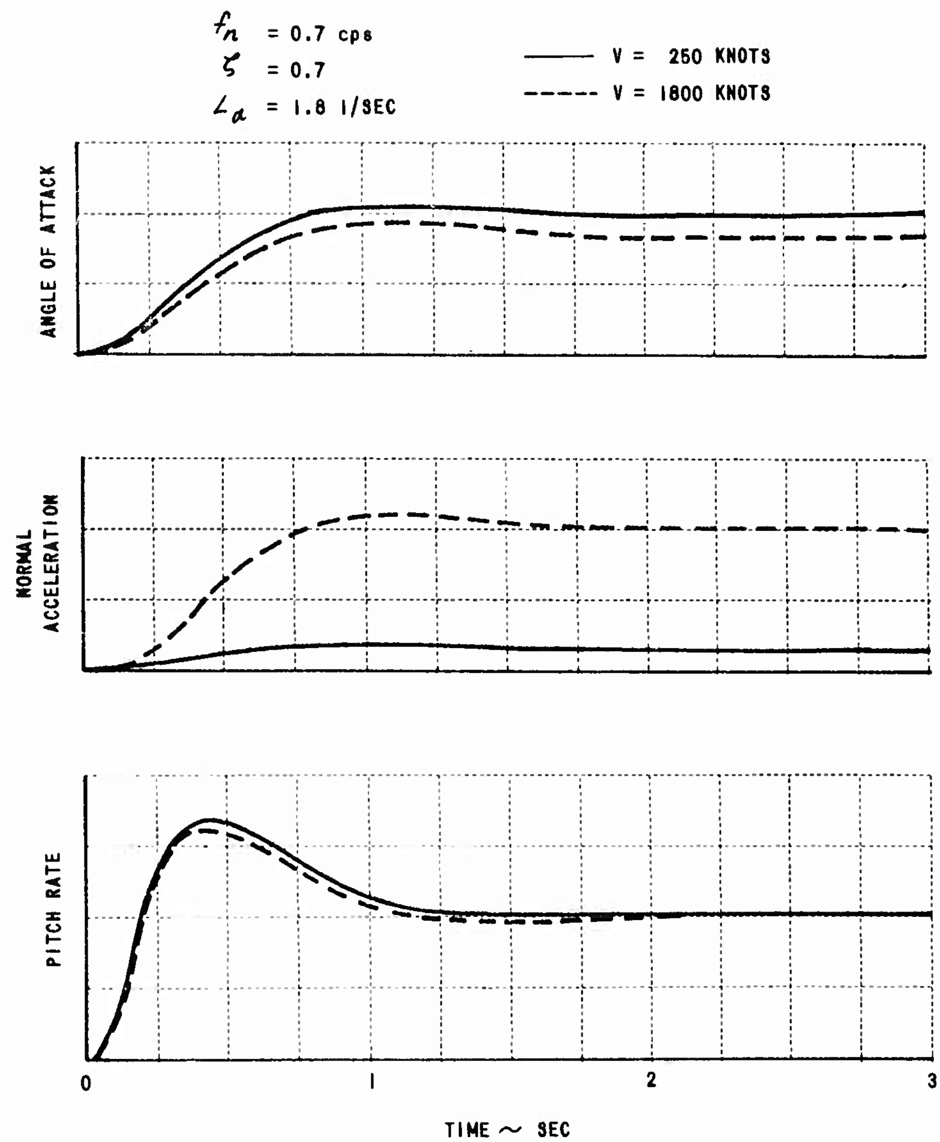


FIGURE 1 COMPARISON OF RESPONSES TO STEP ELEVATOR AT TWO SPEEDS

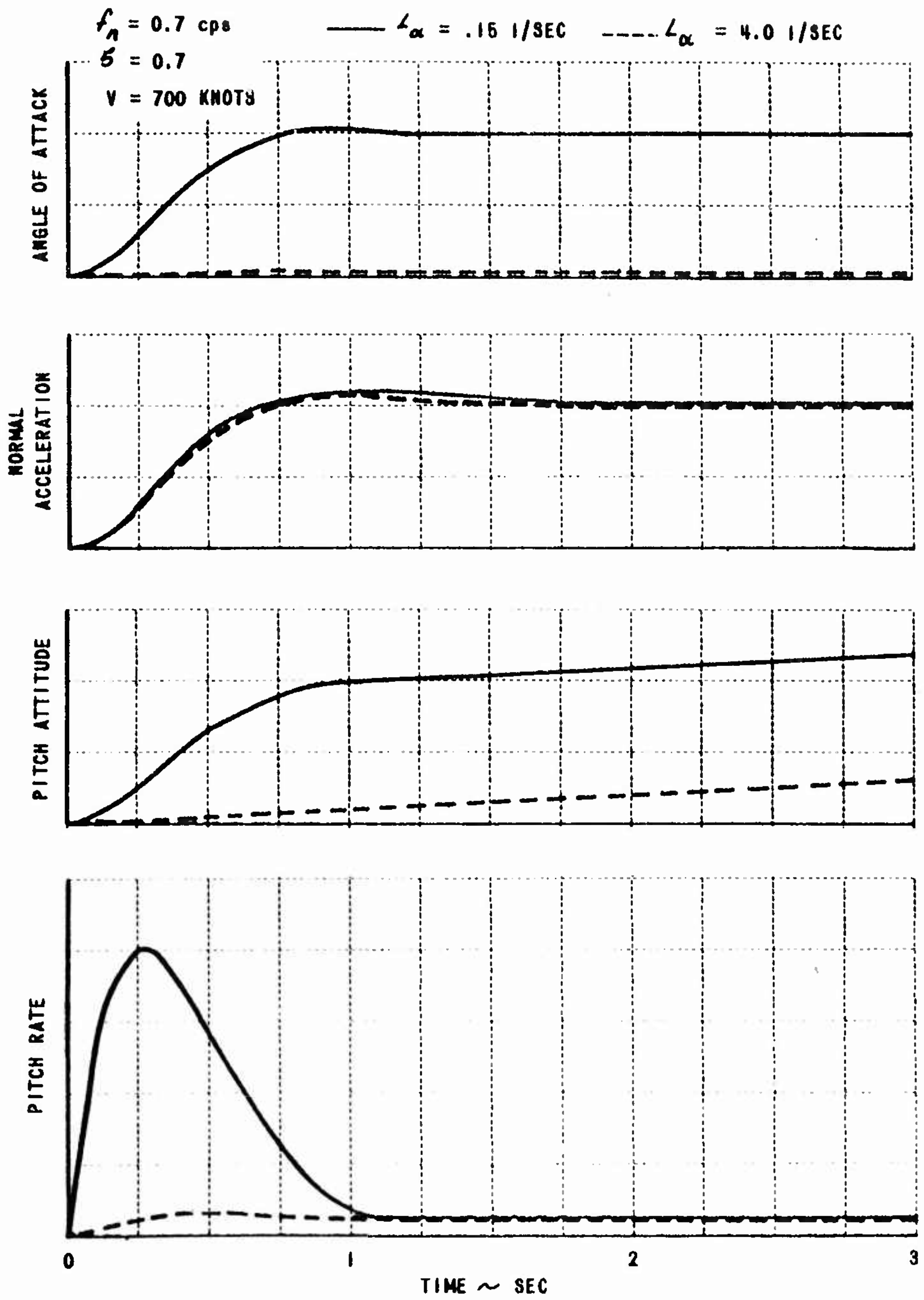


FIGURE 2 COMPARISON OF RESPONSES TO STEP ELEVATOR FOR TWO VALUES OF L_α

Figure 1 illustrates the relative magnitudes of vehicle responses at two speeds, assuming that the elevator input has been adjusted to give the same steady state pitch rate in each case. The large difference in normal acceleration for the same pitch rate at the two true speeds is of course a result of kinematics and is independent of the aircraft type or configuration.

Figure 2 illustrates the relative magnitude and phase of vehicle responses for two values of L_α. In this figure, the elevator inputs have again been adjusted to give the same steady pitch rate for the two airplanes being compared.

Here it is seen that the steady state angle of attack required to achieve the steady pitch rate is much larger for the low L_α case. The two steady state angles of attack are different by the inverse ratio of the L_α values.

The normal acceleration responses are nearly identical for the two cases. This is because the short period frequency and damping ratio, the true speed, and the steady pitch rates are equal for the two cases.

The pitch attitude response is seen to be greatly different for the two values of L_α considered. Pitch attitude is the sum of flight path angle and angle of attack. Since the normal acceleration responses are identical, the flight path angles are also identical. Thus the large pitch attitude change for the low L_α case is a reflection of the large change in angle of attack required to achieve the steady pitch rate.

Although the steady pitch rate responses are equal for the two airplanes, it is seen that the initial pitch rates are grossly different. The initial pitch rate for the low L_α case is approximately sixteen times as large as the final value. The magnitude of this overshoot is dependent on the value of L_α, which establishes the amplitude of the pitch attitude transient, and on the short period frequency and damping ratio which defines the nature of the transient.

In view of the above discussion, it is seen that depending on the values of L_α and V the relative magnitude of n_z and α can be grossly different, the initial pitch rate and the steady state pitch rate may be grossly different, the relative magnitude of normal acceleration and steady pitch rate may be greatly different, and the attitude changes required to maneuver may be extreme or minute.

The ground simulator program conducted was designed to explore the effects on pilot rating of longitudinal flying qualities which might result from large changes in the relative magnitude and phase of the airplane responses obtained by various combinations of L_α and V.

2.2 EXISTING SHORT PERIOD DATA

As indicated in the introduction, considerable empirical handling quality research has been directed at defining acceptable and minimum flyable longitudinal short period dynamics for piloted aircraft. Figure 3 is a summary plot of much of these data with references indicated.

These data indicate the same general conclusions as to which areas of short period "stiffness" and "damping" contribute to good flying qualities and which areas contribute to bad flying qualities; however, the data do not always agree in detail.

The tests from which these data were obtained were done at specific flight conditions such that the parameter L_α and the true speed were constant for all configurations in each test series. Although these parameters were maintained constant during each test series, they were not equal from one series to another. The nominal values existent during each test series were as follows:

F-94 data	Reference 13	$L_\alpha = 1.39$	V = 398 kt	$L_\alpha V/g$	= 29 g/rad
F-94 data	Reference 4	$L_\alpha = 1.90$	V = 440 kt	$L_\alpha V/g$	= 44 g/rad
T-33 data	Reference 8	$L_\alpha = 1.25$	V = 375 kt	$L_\alpha V/g$	= 25 g/rad
B-26 data	Reference 5	$L_\alpha = 1.20$	V = 203 kt	$L_\alpha V/g$	= 13 g/rad
B-26 data	Reference 6	$L_\alpha = 0.83$	V = 120 kt	$L_\alpha V/g$	= 5.2 g/rad
Centrifuge Data	Reference 11	$L_\alpha = 1.0$	V = ?	$L_\alpha V/g$	= ?

In addition to the differences in L_α and true speed, there are several other possible reasons for the disagreement in detail which should be noted. For example, there were differences in:

1. The vehicle type and the mission definition,
2. The rating scale definition,
3. Pilot evaluation criterion and experience,
4. The type controller and controller characteristics,
5. The extent of each test series.

Thus the exact cause of the observed differences in pilot rating may never be determined for these particular data.

Because of the greatly expanded flight envelope, values of L_α and true speed greatly different from those existent in any of the referenced tests are possible for current and future piloted vehicles (extreme values of L_α and V can result from various combinations of vehicle design, vehicle configuration, and flight condition). For this reason, the ground simulator program was designed to explore the effects of L_α and true speed on pilot rating of longitudinal flying qualities and on the optimum control gain at the three short period poles indicated by the O's in Figure 3.

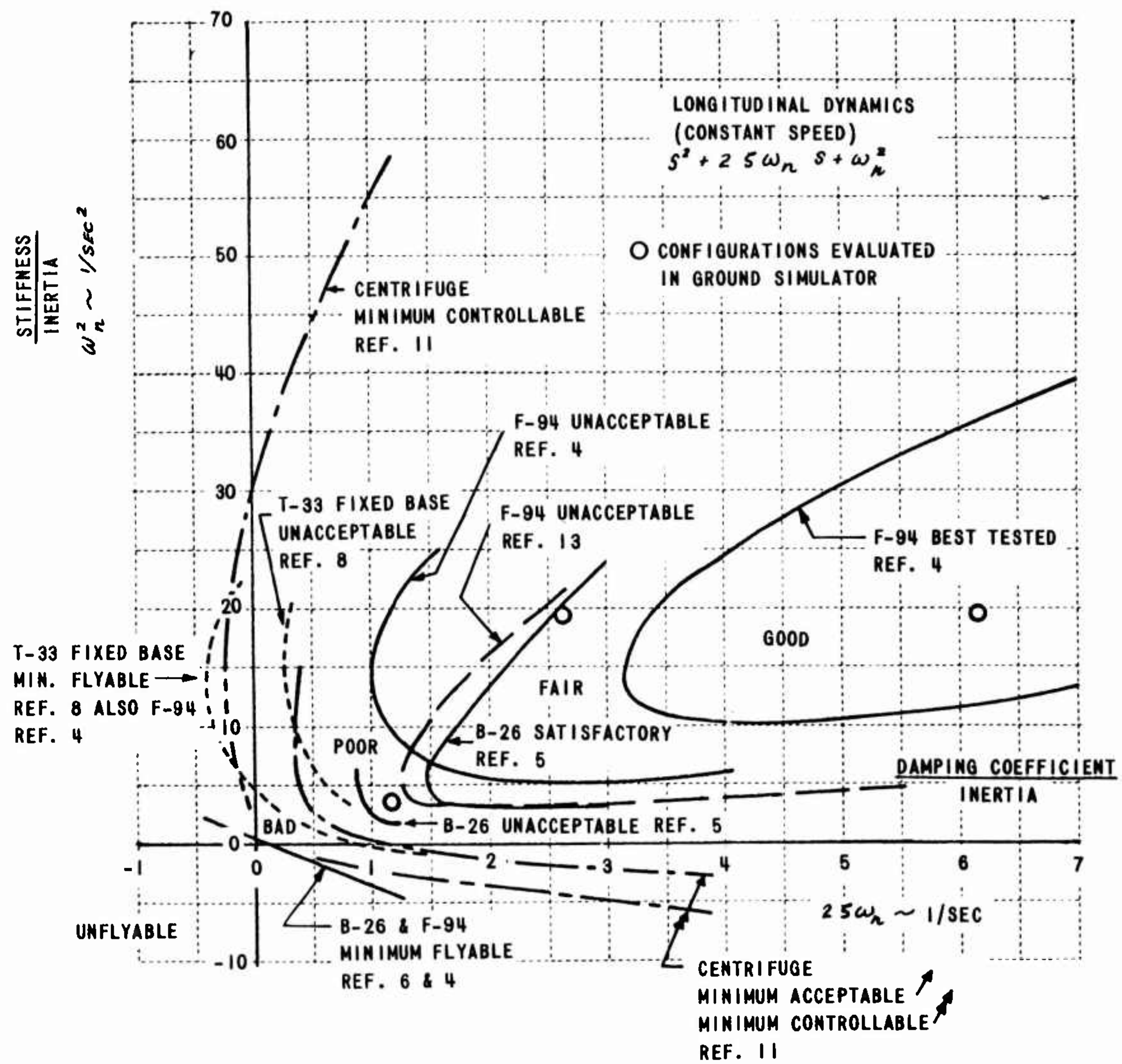


FIGURE 3 LONGITUDINAL SHORT PERIOD DYNAMICS FLYING QUALITIES DATA FOR FIGHTER AND LIGHT BOMBER AIRCRAFT

2.3 LONGITUDINAL CONTROL GAINS

The gain constants of the factored transfer functions developed in Appendix C, Equations C-13 through C-15, express the steady state ratio of the magnitude of each airplane response to the magnitude of an elevator step input.

$$K'_{\alpha} = \frac{M_{\delta} + M_q L_{\delta}}{-M_{\alpha} - M_q L_{\alpha}} \approx \frac{M_{\delta}}{\omega_n^2} \qquad \text{(C-13)}$$

$$K_{\dot{\theta}} = \frac{M_{\delta} L_{\alpha} - M_{\alpha} L_{\delta}}{-M_{\alpha} - M_q L_{\alpha}} \approx \frac{M_{\delta} L_{\alpha}}{\omega_n^2} \qquad \text{(C-14)}$$

$$K_{n_z} = \frac{V}{g} K_{\dot{\theta}} = \frac{V}{g} \frac{M_{\delta} L_{\alpha}}{\omega_n^2} \qquad \text{(C-15)}$$

If these gains are multiplied by the gear ratio relating stick displacement to elevator displacement, the gains between pilot input and airplane responses are obtained. These gains are illustrated by sketches of asymptotic Bode plots in Figure 4. The steady state (assuming constant speed and negligible elevator lift) angle of attack gain is the same as the pitch attitude gain at the short period, the steady state pitch rate gain is L_{α} times the angle of attack gain, and the normal acceleration gain is $V/g\, L_{\alpha}$ times the angle of attack gain. From these relationships it is seen that depending on which response is of primary concern to the pilot, the gearing may or may not need to be modified as velocity or L_{α} change.

In the ground simulator program, the pilots were asked to select the stick to elevator gear ratio which they considered most compatible with each configuration evaluated. Thus, for example, if the pilot preferred constant steady state pitch rate gain we would expect him to select a different value of $\frac{\delta_e}{\delta_s} M_{\delta}$ when ω_n^2 or L_{α} was changed but not when the velocity was changed.

In this way data were collected to determine the functional relations which might exist between the pilot selected values of the gains defined in Figure 4 and the independent variables V, L_{α} and ω_n .

2.4 LONGITUDINAL RESPONSE TO TURBULENCE

An important consideration in the evaluation of an aircraft from the handling qualities point of view is its response to atmospheric turbulence. The acceleration environment that the pilot and crew must endure is determined by the turbulence characteristics and by the response of the aircraft to the turbulence.

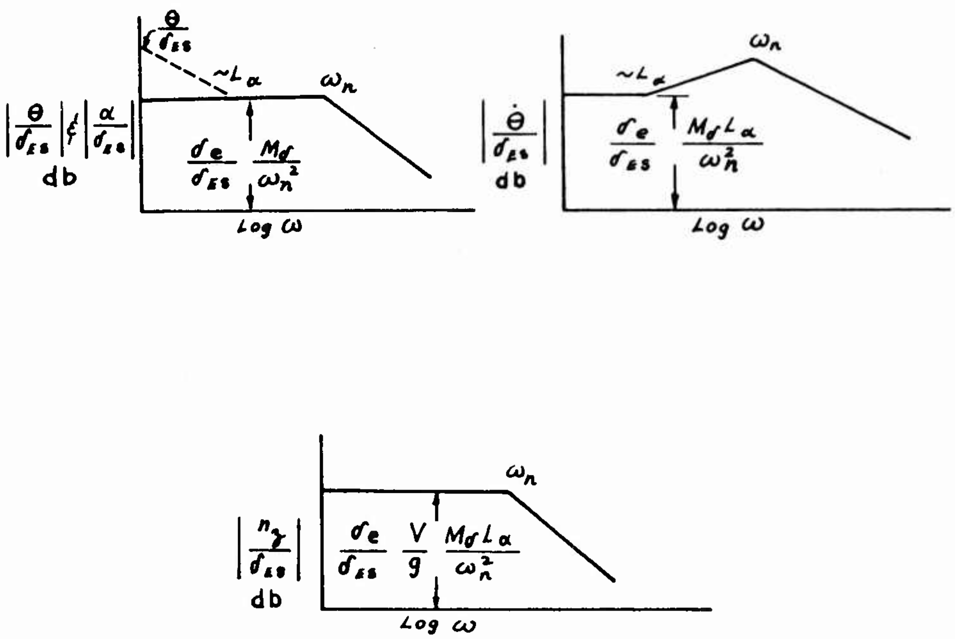


FIGURE 4 APPROXIMATE ASYMPTOTIC LONGITUDINAL FREQUENCY RESPONSES (CONSTANT SPEED AND NEGLIGIBLE ELEVATOR LIFT)

For the evaluation program considered herein, it was decided to use a simplified simulation of the vertical velocity component of atmospheric turbulence.

The details of this turbulence simulation and the spectral distribution of the turbulence input used in the experiment are described in Appendix A. 2 and illustrated in Figure A.4.

The equations and transfer functions relating the response of the center of gravity of a rigid airplane to the simulated vertical gust velocity input are derived in Appendix C. 2.

The normal acceleration response of the uncontrolled airplane to vertical gust inputs is expressed in transfer function form by equation C-35.

$$\frac{n_z(s)}{w_{a.g.}(s)} = \frac{L_\alpha}{g} \frac{s\left[s-(M_q+M_{\dot{\alpha}})\right]}{\left[s^2+2\zeta\omega_n s+\omega_n^2\right]} \qquad \text{(C-35)}$$

The magnitude of the amplitude ratio of this transfer function as a function of frequency is illustrated by the sketch of Figure 5. From equation C-35 and the sketch of Figure 5 it is seen that at very low frequency the acceleration response is low while at high frequency the acceleration response is equal to L_α / g. The response at intermediate frequencies is determined by the short period frequency and damping ratio, and by the numerator break point at $\omega = |M_q + M_{\dot{\alpha}}|$.

The normal acceleration response would be expected to be a minimum for a low value of L_α and a high short period natural frequency.

The effect of increasing short period damping is to reduce the response at the short period frequency and to increase the response at low frequency due to the larger value of $|M_q + M_{\dot{\alpha}}|$. For constant L_α and ω_n, the short period damping ratio can only be increased by increasing $|M_q + M_{\dot{\alpha}}|$, thus increasing the response at low frequency.

The net normal acceleration frequency spectra can be obtained by combining the simulated turbulence spectra of Figure A-2 with the airplane transfer function C-35. This has been done for each of the three short period poles of Figure 5 for L_α = 4 and V = 250 knots. The resulting normal acceleration frequency spectra are plotted in Figure 6.

The following equations detail the procedure.

C_η (White noise) → $\boxed{KG(j\omega)}$ Filter → $\phi_T(\omega)$ (Turbulence Power Spectrum) → $\boxed{Y(j\omega)}$ Airplane → $\phi_{n_z}(\omega)$ (Normal Acceleration Power Spectrum)

where $\phi_{n_z}(\omega) = C_\eta \left|KG(j\omega)\right|^2 \left|Y(j\omega)\right|^2$

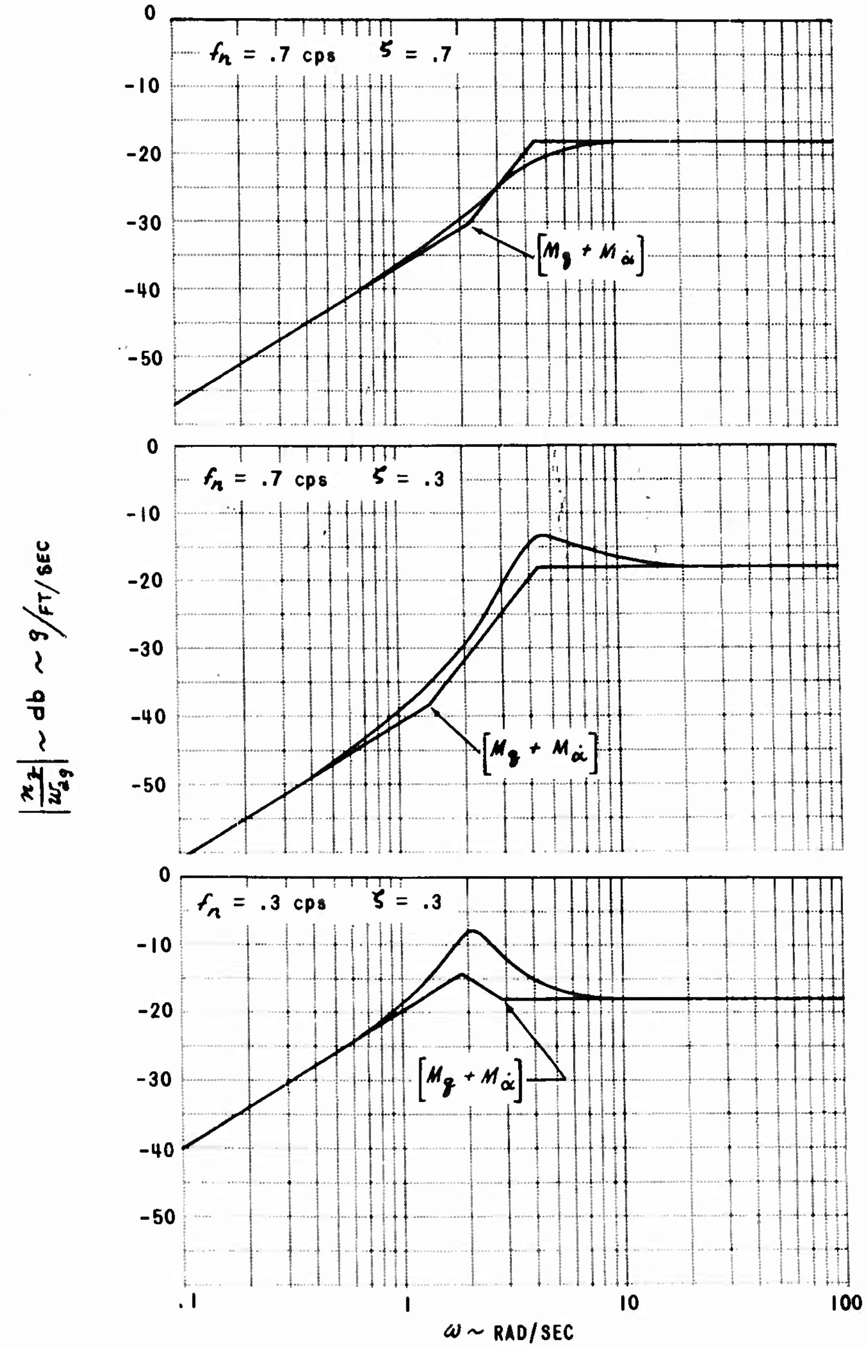


FIGURE 5 FREQUENCY RESPONSES OF NORMAL ACCELERATION RESPONSE TO VERTICAL GUST INPUT

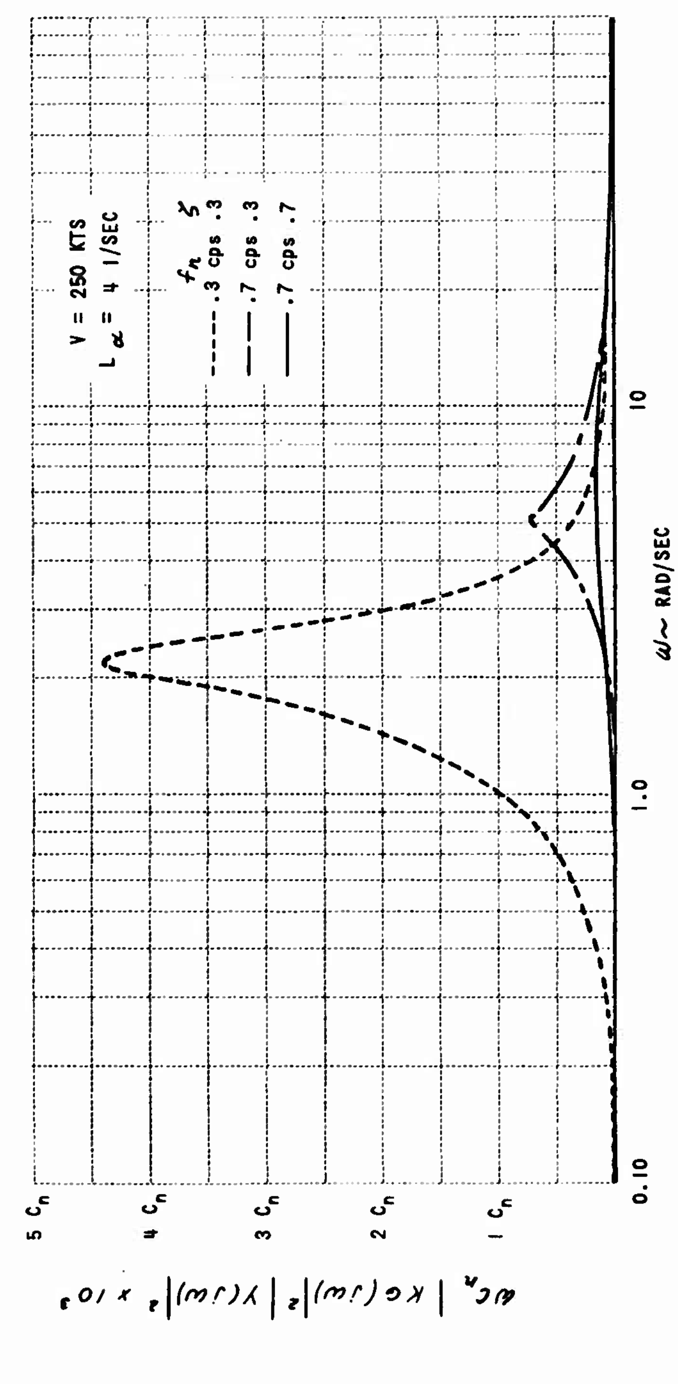


FIGURE 6 NORMAL ACCELERATION RESPONSE TO SIMULATED TURBULENCE

For the plot of Figure 6 the power spectra has been multiplied by ω and plotted versus frequency on a logarithmic scale to give a graphic picture of the normal acceleration response. The mean square normal acceleration is expressed by the following equation

$$\overline{\phi^2_{n_z}} = \int_{-\infty}^{\infty} C_n \left|KG(j\omega)\right|^2 \left|Y(j\omega)\right|^2 d\omega$$

If this equation is multiplied and divided by ω

$$\overline{\phi^2_{n_z}} = \int_{-\infty}^{\infty} \omega C_n \left|KG(j\omega)\right|^2 \left|Y(j\omega)\right|^2 \frac{d\omega}{\omega}$$

and if it is noted that $\frac{d\omega}{\omega} = d(\ln \omega)$ then the expression for the mean square normal acceleration can be written

$$\overline{\phi^2_{n_z}} = \int_{-\infty}^{\infty} \omega C_n \left|KG(j\omega)\right|^2 \left|Y(j\omega)\right|^2 d(\ln \omega)$$

If $\omega C_n \left|KG(j\omega)\right|^2 \left|Y(j\omega)\right|^2$ is plotted versus ω using a logarithmic scale for the frequency, then the shape of the resulting curve illustrates at a glance the frequencies which contribute most to $\overline{\phi^2_{n_z}}$ since the area under the curve is proportional to the mean square normal acceleration.

The three curves of Figure 6 graphically illustrate the effect of short period frequency and damping ratio on the normal acceleration response to vertical gusts.

The low short period frequency, low damping ratio configuration has much larger response than the high frequency, low damping configuration and the latter has a considerably larger response than the high frequency, high damping ratio configuration at the same short period frequency. However, the high frequency, high damping ratio configuration has a somewhat larger response at low frequencies than does the high frequency, low damping ratio configuration.

The ground simulator program was also designed to obtain systematic data on the effects and interactions of the many factors which contribute to the flying qualities of an aircraft flying in turbulent air.

SECTION 3

EXPERIMENTAL PROCEDURE

3.1 EXPERIMENT DESIGN

The experiment consisted of a ground simulator program to explore the effects of L_α and true speed on pilot opinion of longitudinal flying qualities and optimum elevator control sensitivity. Tests were conducted for various combinations of L_α and V at each of three short period pole locations. The numerical values of the various parameters studied are listed below.

Short Period Poles

$f_n \sim$	.7 cps	.7 cps	.3 cps
$\zeta \sim$	.7	.3	.3

The location of these poles relative to the handling quality boundaries established by previous experiments is shown in Figure 3.

True Speed Values

V~ 130 knots 250 430 700 1100 1800

L_α Values

$L_\alpha \sim$ .07 .15 .50 1.8 4.0

The following tables indicate in a concise form the combinations of these parameters that were studied.

It will be noted that only three configurations were studied at the 130 knot speed. For the 1800 knot speed, the L_α = 4 configuration was omitted and L_α = .07 was added in all cases.

TABLE 1 $\left.\begin{matrix} f_n = .7 \\ \zeta = .7 \end{matrix}\right\}$ and $\left\{\begin{matrix} f_n = .7 \\ \zeta = .3 \end{matrix}\right.$

V	L_α .07	.15	.50	1.8	4.0
130 knots	-	-	-	-	-
250	-	x	x	x	x
430	-	x	x	x	x
700	-	x	x	x	x
1100	-	x	x	x	x
1800	x	x	x	x	-

Combinations marked with (x) were studied.

TABLE 1 (continued)

$f_n = .3$

$\zeta = .3$

V	L_α .07	.15	.50	1.8	4.0
130 knots	-	x	x	x	-
250	-	x	x	x	x
430	-	x	x	x	x
700	-	x	x	x	x
1100	-	x	x	x	x
1800	x	x	x	x	-

Combinations marked with (x) were studied.

Two primary pilots and one backup pilot participated in the program. The two primary pilots completed all 63 of the configurations plus 15 planned repeats and 4 to 6 selected repeats. The third pilot completed approximately one-third of the basic 63 configurations.

In conducting the tests the computer and instrument display were set up for a given velocity and then each of the possible combinations of four values of L_α and three short period poles was studied. For each such group of twelve configurations, one configuration was repeated three times. Thus, at each speed a set of fifteen configurations was studied. An exception to this schedule was the V = 130 knot speed for which only three values of L_α were studied at one short period pole.

The following tables define the configurations and the order in which they were done by Pilots A and B. The order in which the configurations were studied was random or at least arbitrary. The pilots had no foreknowledge of the particular configurations that were presented to them.

TABLE 2

Pilots A and B

V = 250 knots

Short Period	L_α				
	.07	.15	.50	1.8	4.0
$f_n = .7$, $\zeta = .7$	-	4	3	15	7
$f_n = .7$, $\zeta = .3$	-	9	10	5	11
$f_n = .3$, $\zeta = .3$	-	1, 6, 12, 14	8	13	2

V = 430 knots

Short Period	L_α				
	.07	.15	.50	1.8	4.0
$f_n = .7$, $\zeta = .7$	-	19	18	16, 21, 27, 29	22
$f_n = .7$, $\zeta = .3$	-	24	25	20	26
$f_n = .3$, $\zeta = .3$	-	30	23	28	17

V = 700 knots

Short Period	L_α				
	.07	.15	.50	1.8	4.0
$f_n = .7$, $\zeta = .7$	-	34	33	45	37
$f_n = .7$, $\zeta = .3$	-	39	40	31, 36, 42, 44	41
$f_n = .3$, $\zeta = .3$	-	35	38	43	32

V = 1100 knots

Short Period	L_α				
	.07	.15	.50	1.8	4.0
$f_n = .7$, $\zeta = .7$	-	49	46, 51, 57, 59	60	52
$f_n = .7$, $\zeta = .3$	-	54	55	50	56
$f_n = .3$, $\zeta = .3$	-	48	53	58	47

V = 1800 knots

Short Period	L_α				
	.07	.15	.50	1.8	4.0
$f_n = .7$, $\zeta = .7$	64	63	75	67	-
$f_n = .7$, $\zeta = .3$	69	70	65	71	-
$f_n = .3$, $\zeta = .3$	61, 66, 72, 74	68	73	62	-

V = 130 knots

Short Period	L_α				
	.07	.15	.50	1.8	4.0
$f_n = .7$, $\zeta = .7$	-	-	-	-	-
$f_n = .7$, $\zeta = .3$	-	-	-	-	-
$f_n = .3$, $\zeta = .3$	-	77	78	76	-

Note: The numbers in the table refer to the sequence in which the configurations were studied.

In addition to the planned repeats which appear in the tables, the following configurations were also repeated by pilots A and B.

Pilot	Configuration
A	2, 20, 26, 45
B	2, 5, 7, 40, 56, 58

The third pilot completed the configurations defined in the tables below. This pilot was used in the program to verify trends in the data and to relieve scheduling difficulties that might have been encountered with only two pilots participating.

TABLE 3

Pilot C

V = 250 knots

Short Period	L_α				
	.07	.15	.50	1.8	4.0
f_n = .7	-	15	14, 25	17	16
ζ = .7	-	-	-	-	-
f_n = .7, ζ = .3	-	-	-	-	-
f_n = .3, ζ = .3	-	-	-	-	-

V = 430 knots

Short Period	L_α				
	.07	.15	.50	1.8	4.0
f_n = .7, ζ = .7	-	-	-	-	-
f_n = .7, ζ = .3	-	22	24	23	26
f_n = .3, ζ = .3	-	-	-	-	-

V = 700 knots

Short Period	L_α				
	.07	.15	.50	1.8	4.0
f_n = .7, ζ = .7	-	11	6	13	12
f_n = .7, ζ = .3	-	-	-	-	-
f_n = .3, ζ = .3	-	2	1	3	4, 5

V = 1100 knots

Short Period	L_α				
	.07	.15	.50	1.8	4.0
f_n = .7, ζ = .7	-	-	-	-	-
f_n = .7, ζ = .3	-	8	9	10	7
f_n = .3, ζ = .3	-	-	-	-	-

V = 1800 knots

Short Period	L_α				
	.07	.15	.50	1.8	4.0
f_n = .7, ζ = .7	19	18	21	20	-
f_n = .7, ζ = .3	-	-	-	-	-
f_n = .3, ζ = .3	-	-	-	-	-

The following data were recorded for each configuration:

1. Optimum elevator gear ratio
2. Pilot ratings
3. Pilot comment data
4. Aircraft response to
    a. Elevator pulse input
    b. Elevator step input
    c. Throttle step input
    d. Two-minute sample of pilot attempting to minimize disturbances to attitude, altitude and airspeed in rough air.

Items 1, 2, and 3 form the bulk of the data and are analyzed in the following sections. The oscillograph records of aircraft responses were used mainly to establish proper operation of the simulation equipment.

3.2 DESCRIPTION OF THE SIMULATOR

The general arrangement of the T-33 fixed-base or ground simulator is shown in Figure A-1. The airplane is parked in the corner of the flight hangar and connected through cabling to an analog computer in an adjoining room. The variable stability equipment is powered by a rectifier and the hydraulic servos are supplied by a hydraulic mule. The pilot sits in the front cockpit, which is covered, and "flies" the airplane using the two-axis side stick (Figure A-2), rudder pedals and a simulated throttle. The side stick produces an electrical signal proportional to displacement with feel provided by springs and Teflon disc dampers. The rudder pedals are positioned by the pilot's feet and produce electrical signals proportional to displacement. The rudder pedal feel is provided by feel servos. The simulated throttle consisted of a quadrant and lever which positioned a potentiometer. These control signals are used to command the hydraulic servos which position the control surfaces. Position pickups on the control surfaces generate electrical signals which are used together with a signal from the throttle as inputs to the analog computer. With this arrangement the dynamics of the control system are included as part of the simulation.

The analog computer is programmed to solve limited six-degree-of-freedom equations of motion and computes the airplane motions resulting from the pilot's control inputs. The particular equations that were mechanized and the approximations used in their mechanization are detailed in Appendix A.

The computed airplane responses are used to drive the display instruments in the front cockpit of the T-33, thus closing the loop through the pilot. The cockpit display is essentially that used in the X-15 airplane and is pictured in Figure A-3. The active instruments in the display were:

1. Air speed
2. Rate of climb
3. Altitude
4. Pitch and roll attitude
5. Heading
6. Angle of attack
7. Normal acceleration
8. Sideslip
9. Rate of turn

Pitch and roll attitude, sideslip, and rate of turn were displayed on the Lear Remote Attitude-Directional Indicator. See Reference 1 for description of instruments used in the display and of the side controller.

Although the computer mechanization permits making lateral derivatives functions of angle of attack, this provision was not used in the experiments reported here. Since the study was directed at longitudinal handling quality problems and configurations were planned which would require large differences in the magnitude of angle of attack required for maneuvering, it was decided that the data analysis would be more straightforward if the lateral dynamics were made the same for all configurations.

Since this program involved combinations of L_α and true speed which cannot be duplicated by the T-33 in flight, the changes in airplane characteristics were accomplished by appropriate coefficient settings on the analog computer rather than by using the variable stability system gain controls in the airplane. This arrangement minimized the crew required to run the tests and reduced the amount of equipment to be maintained and calibrated.

The 18-channel oscillograph installed in the T-33 was used to record the parameters listed below:

1. δ_{ES} Elevator side stick deflection
2. δ_e Elevator deflection
3. δ_r Rudder deflection
4. δ_T Throttle deflection
5. ψ Heading angle
6. ϕ Roll angle
7. θ Pitch angle
8. q Pitch rate
9. $\dot{q}$ Pitch acceleration
10. ΔV Incremental velocity
11. $\Delta\dot{V}$ Rate of change of incremental velocity
12. β Sideslip angle
13. α Angle of attack
14. $\dot{\alpha}$ Rate of change of angle of attack
15. n_z Normal acceleration
16. Δh Incremental altitude
17. $w_{a.g.}$ Vertical gust velocity

3.3 SUBJECTS IN THE EXPERIMENT

The three pilots who participated in this program are all members of the Flight Research Department at Cornell Aeronautical Laboratory, Inc. Two have engineering degrees and all have participated in various handling quality evaluation programs in the past. A summary of flight time and aircraft type flown by each is contained in Table 4.

TABLE 4

PILOT EXPERIENCE

Type of Aircraft	Number of Hours Pilot A	Pilot B	Pilot C
Jet	1500	1225	600
Reciprocating Engine	6000	1860	2800
Helicopter	500	-	-

3.4 INSTRUCTIONS TO PILOTS

The briefing instructions to the pilots who participated in the program were formalized in a memorandum and a set of "flight cards". These instructions established the frame of reference in which the evaluations were performed and are reproduced in Appendix B.

The pilots were instructed to select the elevator gear ratio that they considered most compatible for each configuration and to conduct their evaluation using this "optimum" elevator control sensitivity. The evaluations were conducted in two parts and two ratings were assigned to each configuration. The first part of the evaluation was conducted in "smooth air", i.e., no external disturbances to the airplane. Upon completion of the smooth air evaluation and rating, the pilots examined the configurations in simulated rough air (see Section A.2 of Appendix A). This part of the evaluation was conducted to determine whether the rough air caused any particular difficulties in control and to determine the severity of the ride that might be expected for flight in continuous turbulence.

The recommended evaluation maneuvers, the comment check list, and the rating scale used in the program are contained in Appendix B.

3.5 EVALUATION CRITERIA

The study was intended to be a general survey or exploration of the effects on pilot ratings and optimum longitudinal control sensitivity of true speed and L_α. Because the study was a general one and the range of velocity and L_α was so wide, it was not possible to define a single vehicle or a specific mission for the evaluations. Therefore, the vehicle type was left undefined except that it was a powered lifting vehicle capable of the speed displayed to the pilot. The airplanes were assumed to be in "up and

away" flight under instrument conditions and the evaluation task was made the general one of maintaining precise control of the flight path of the vehicle through space.

Thus, the smooth air ratings were based on the amount of effort the pilot was required to put forth to achieve the precision offlight path control that he considered satisfactory. The ratings were determined individually while each pilot actually performed the task, or at least the components of the task. He evaluated the effort, skill, concentration, and the practicability of any special techniques required to accomplish the task, as well as his performance in actually accomplishing it. The rating also reflected whether or not the configuration possessed any characteristic which the pilot considered potentially dangerous or unforgiving.

The rough air rating was intended to reflect any control difficulties caused by external disturbances and to indicate the severity of the ride that might be expected in continuous turbulence. All three pilots adopted the philosophy that their ability to control the flight path could never be better in rough air than it was in smooth air. Thus, the ratings after rough air either were the same as the smooth air rating or reflected a degradation from the smooth air rating because of control difficulties or an intolerable indicated acceleration environment.

SECTION 4

RESULTS OF THE EXPERIMENT

4.1 OPTIMUM LONGITUDINAL GAIN

4.1.1 Side Controller Characteristics

The two-axis side controller (Figure A-2) used in the simulation program is essentially a copy of the side controller used in the X-15 airplane. (This unit was originally used in a flight program directed at simulation of the handling qualities of the X-15 during re-entry.)

The torque-displacement characteristics of the side controller are illustrated by the calibration plot of Figure 7. The device exhibits a number of nonlinearities such as: near-zero spring rate around zero displacement, breakout forces or preload, and nonuniform hysteresis or friction.

The optimum longitudinal control gain data will be presented and discussed in the following sections in terms of stick displacement. To present the control gain data in terms of stick force or torque it would be necessary to linearize the side controller characteristics. Rather than do this, the side controller torque-displacement characteristics are presented separately in Figure 7 and the control gain data will be presented in terms of stick deflection. This should not, however, be interpreted as implying that the pilot flies the airplane by stick deflection rather than stick force.

4.1.2 Optimum Gains as Function of n_z/α

The pilot-selected gear ratio data were used to compute the following approximate transfer function gains (see Appendix C and Section 2.3 for development).

$$\frac{\delta_e}{\delta_{ES}} K_\alpha \approx \frac{\delta_e}{\delta_{ES}} \frac{M_\delta}{\omega_n^2}$$

$$\frac{\delta_e}{\delta_{ES}} K_{\dot{\theta}} \approx \frac{\delta_e}{\delta_{ES}} \frac{M_\delta L_\alpha - M_\alpha L_\delta}{\omega_n^2}$$

$$\frac{\delta_e}{\delta_{ES}} K_{n_z} \approx \frac{\delta_e}{\delta_{ES}} \frac{V}{g} \frac{M_\delta L_\alpha - M_\alpha L_\delta}{\omega_n^2}$$

The computations are tabulated in Appendix D Table D-4. It should be noted that the inclusion of the term $M_\alpha L_\delta$ in the definition of the pitch rate and normal acceleration gains only modifies the values of these gains by a few percent. This is true for the simulation study because L_δ was

NOTE: TO CONVERT TORQUE TO FORCE AT PRESSURE POINT DIVIDE BY 2.45 IN.

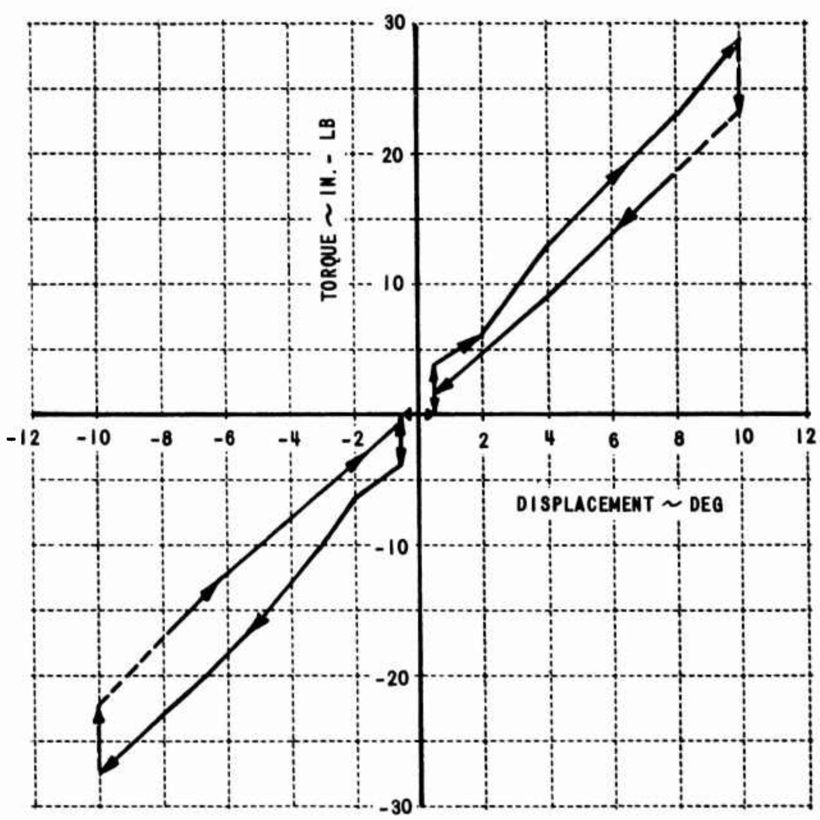


FIGURE 7 SIDE CONTROLLER CHARACTERISTICS - LONGITUDINAL

adjusted for each configuration as discussed in Appendix C and the term $M_\alpha L_\delta$ was always small compared to $M_\delta L_\alpha$.

In the analysis of the longitudinal gain data, the steady state α/δ_{ES}, n_z/δ_{ES} and $\dot{\theta}/\delta_{ES}$ gains were plotted vs. both L_α and true speed. Also, three-dimensional models were made in which each gain was represented as altitude above a plane with coordinates of L_α and V on the plane. From these various ways of looking at the data it was decided that plotting the gain data versus the non-dimensional parameter $L_\alpha V/g$ on log-log grid is the most informative. Assuming constant speed, and neglecting the lift due to elevator, $\frac{L_\alpha V}{g} \approx \frac{n_z}{\alpha}$ (See Figure 4 or Equation C-20 and C-21) It should be noted that for a given lift curve slope and wing loading, $\frac{L_\alpha V}{g}$ is proportional to dynamic pressure.

In Figures 8a, 8b and 8c, the optimum longitudinal control gains selected by pilots A, B and C respectively are plotted for each of the three short period poles.

The plots of Figures 8a, 8b and 8c indicate that the pilots tended to select constant steady state angle of attack gain when $n_z/\alpha < 10$ g/rad, and to select constant steady state normal acceleration gain when $n_z/\alpha > 10$ g/rad.

The steady state pitch rate gains corresponding to the pilot-selected gear ratios form a family of curves with true speed as a parameter. If the steady state pitch rate gain data were multiplied by velocity, the curves would be brought together and tend to form a single function of n_z/α; however, V/g times the steady state pitch rate gain is equal to the steady state normal acceleration gain (see Figure 4) which is already plotted.

The heavy dashed lines in Figures 8a, 8b and 8c were obtained by assuming that the pilots were tending to select constant steady-state angle of attack gain when n_z/α was less than approximately 10 g/rad, and that they were tending to select constant steady state normal acceleration gain when n_z/α was greater than approximately 10 g/rad. The location of the dashed line for each short period is obtained by averaging the values of $\delta_e/\delta_{ES}\ K_\alpha$ for all configurations for which $n_z/\alpha < 10$ g/rad and by averaging the values of $\delta_e/\delta_{ES}\ K_{n_z}$ for all configurations for which $n_z/\alpha > 10$ g/rad.

Pilot B's control gain data and part of pilot C's data show a tendency for the points obtained at $V = 250$ knots to fall below the dashed lines and for the points obtained at $V = 1800$ knots to fall above the dashed lines. This would indicate an independent influence of velocity on the optimum gain, possibly attributable to the desire for lower stick forces in turns (at the high speed a given bank angle will produce a lower rate of turn, thus requiring a longer time to achieve a heading change). Since this tendency is not present in pilot A's data, and since in some cases the variation from repeated runs is as large as pilot B's variation from $V = 250$ knots to $V = 1800$ knots, this indication of an independent influence of velocity is not considered to be a

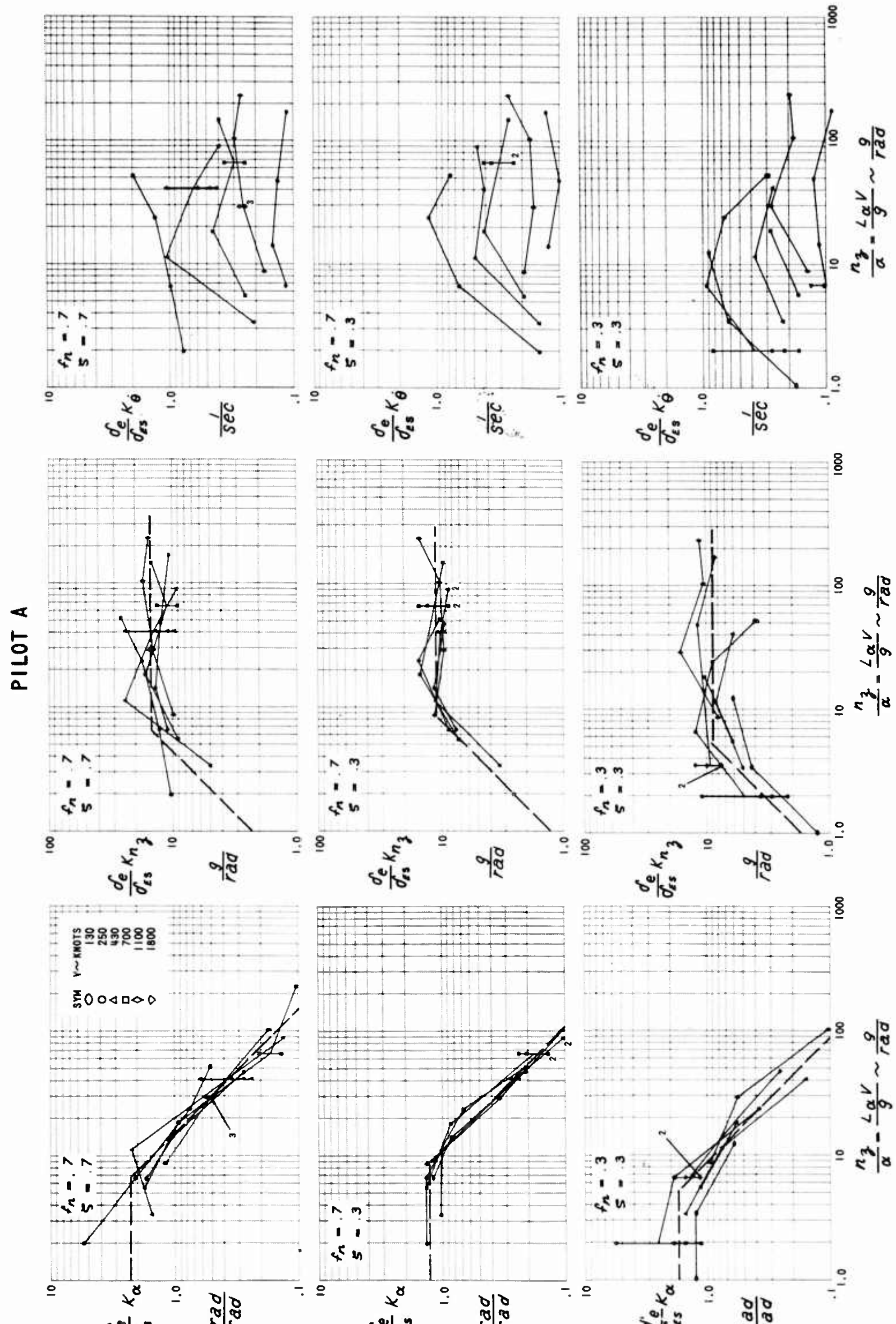


FIGURE 8a OPTIMUM LONGITUDINAL CONTROL GAINS SELECTED BY PILOT A

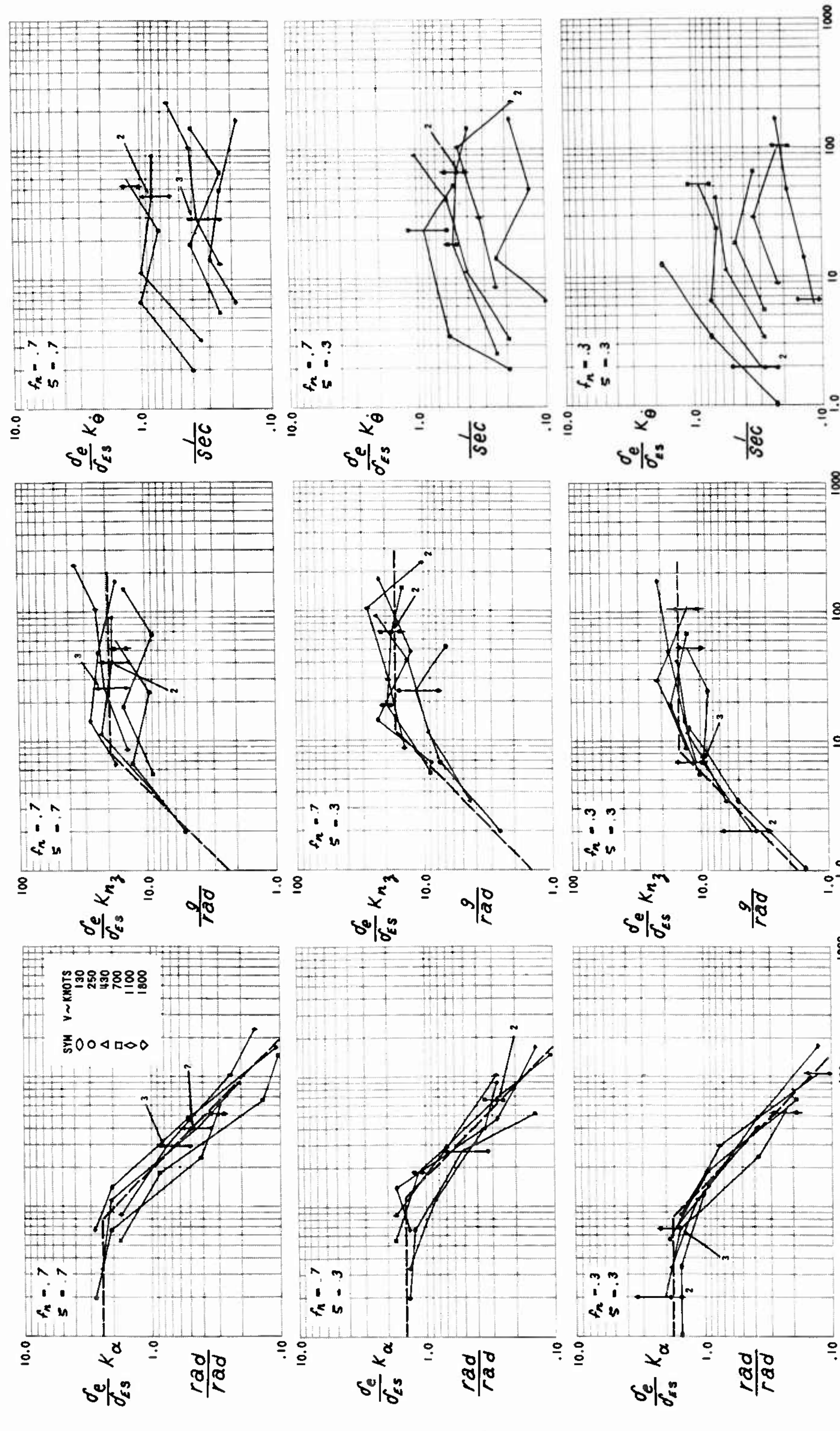


FIGURE 8b OPTIMUM LONGITUDINAL CONTROL GAINS SELECTED BY PILOT B

PILOT C

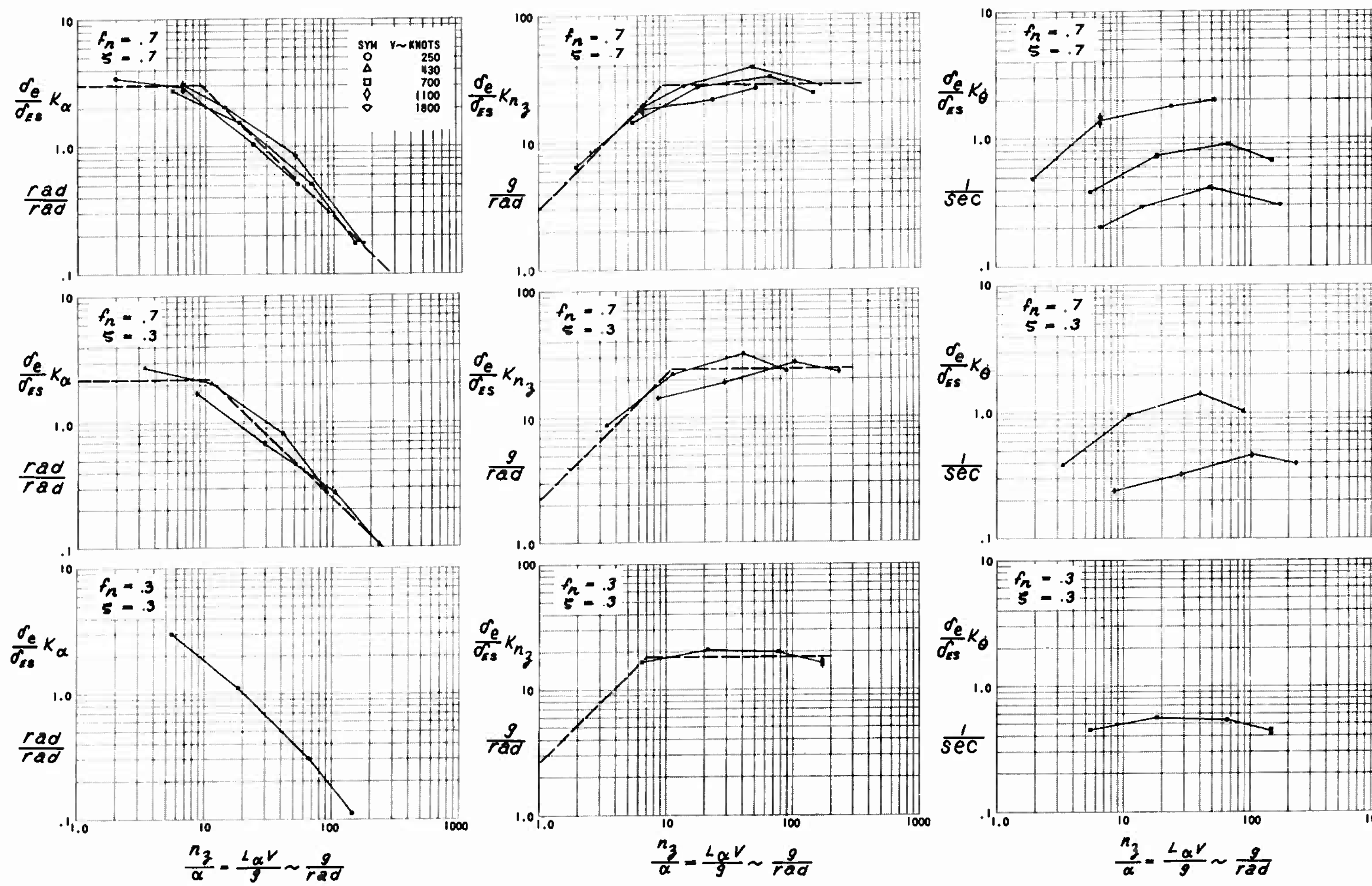


FIGURE 8c OPTIMUM LONGITUDINAL CONTROL GAINS SELECTED BY PILOT C

primary result.

The major trends of the optimum longitudinal gain data are thought to be well represented by the dashed lines in Figures 8a, 8b and 8c. It should be noted that the numerical values of the gains selected are applicable only to the particular side controller used in the experiment. If a side controller of different design were used or if a center stick or wheel were used, the numerical values of the optimum gains would be different in each case but the functional relation with n_z/α would be expected to prevail.

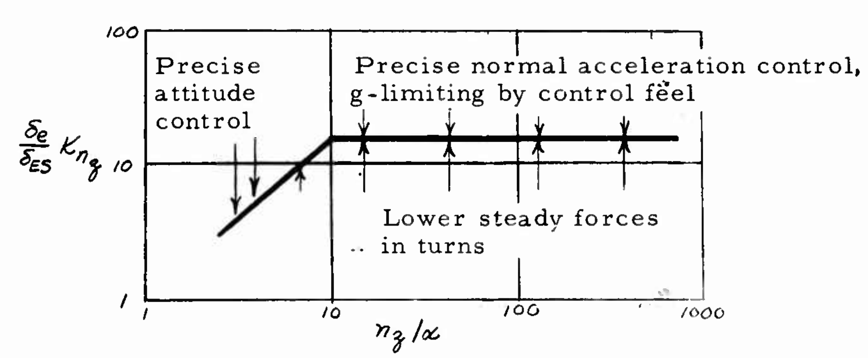
In Reference 12 it was concluded that the airframe attitude gain at short period, i.e., $\frac{\delta_e}{\delta_{ES}} \frac{M_\delta}{\omega_n^2}$, is the gain parameter which the pilots desired to have constant, independent of flight condition or other airframe changes. The results of this experiment support the above conclusion when n_z/α is low and the control task is mainly that of attitude control. When n_z/α is high, however, and normal acceleration control becomes of primary concern the results of this investigation do not agree with those of Reference 12.

The experiments reported in Reference 12 were done using a simplified simulation of the flight control task based on the mechanization of a single transfer function and the display of a single vehicle response to the pilot. Although this approach may have been valid for the purpose of studying a limited task such as attitude tracking, it was a gross simplification of the general flight control task and led to a partly erroneous conclusion regarding desirable longitudinal control gain parameters.

4.1.3 Conflicting Requirements and Their Compromise

Examination of the pilot comments reveals that the optimum longitudinal gains were selected after weighing the often conflicting requirements of good pitch attitude control, adequate g-limiting protection and satisfactory steady forces in turns.

The direction in which each of these factors tended to bias the pilot's choice of longitudinal gain and the range of n_z/α over which this influence was exerted is shown in the following sketch.



The desire for lower steady control forces in turns was present at all values of n_z/α and always tended to increase the gain selected. This requirement has less influence at low n_z/α because the useable bank angle was restricted.

For $n_z/\alpha < 10$ g/rad the pilot's desire for precise pitch attitude control without overshoot and oscillation tended to limit the maximum longitudinal control gain that he would accept.

For $n_z/\alpha > 10$ g/rad the maximum longitudinal control gain was limited by the pilot's desire to have precise control of normal acceleration and to be able to rely on control feel to prevent exceeding the acceleration limits of the airframe.

4.1.4 Effect of Short Period Dynamics

The dashed lines of Figures 8a, 8b and 8c, representing steady state normal acceleration gain have been replotted for each pilot in Figure 9. In this figure the effect of short period frequency and damping ratio on the optimum steady state normal acceleration gain can be seen for each pilot. For high n_z/α, the highest gain was selected for [$f_n = .7, \zeta = .7$] and the lowest gain was selected for [$f_n = .3, \zeta = .3$]. For low n_z/α the highest gain was again selected for [$f_n = .7, \zeta = .7$]; however, the lowest gain was selected for [$f_n = .7, \zeta = .3$]. The data of all three pilots exhibit this trend.

In Section 4.1.3 it was indicated that when n_z/α is low, the optimum longitudinal gain was selected primarily on the basis of steady forces in turns and precise attitude control. The desire for light stick forces in turns requires the control gain to be increased toward the maximum permitted by the stability of the pilot-airplane combination in attitude control; i.e., if the control gain is too high, the pilot tends to overcontrol and oscillate the airplane when attempting to change pitch attitude.

The data of Figures 8a, 8b and 8c indicate that for a given short period frequency, when n_z/α was low the pilots tended to choose constant $\frac{\delta_e}{\delta_{ES}} \frac{M_\delta}{\omega_n^2}$. In discussing these plots this gain was referred to as the steady state angle of attack gain. However, as was indicated in Figure 4, the asymptotic approximation to the pitch attitude gain for frequencies between $\omega = L_\alpha$ and $\omega = \omega_n$ is also equal to $\frac{\delta_e}{\delta_{ES}} \frac{M_\delta}{\omega_n^2}$. The actual attitude gain in this frequency band is a function of the short period frequency and damping ratio and differs from the asymptotic approximation.

In Figure 10 the actual amplitude ratio of the θ/δ_{ES} transfer function (short period approximations) is plotted using the averaged $\frac{\delta_e}{\delta_{ES}} \frac{M_\delta}{\omega_n^2}$ data for each of the three pilots and for each of the three short period poles. $L_\alpha = .15$ for all cases in Figure 10. From this figure it is seen that the gear ratios selected by the pilot resulted in approximately the same pitch attitude gain for all three short period poles in a limited frequency band between $\omega = 2$ rad/sec and $\omega = 3$ rad/sec.

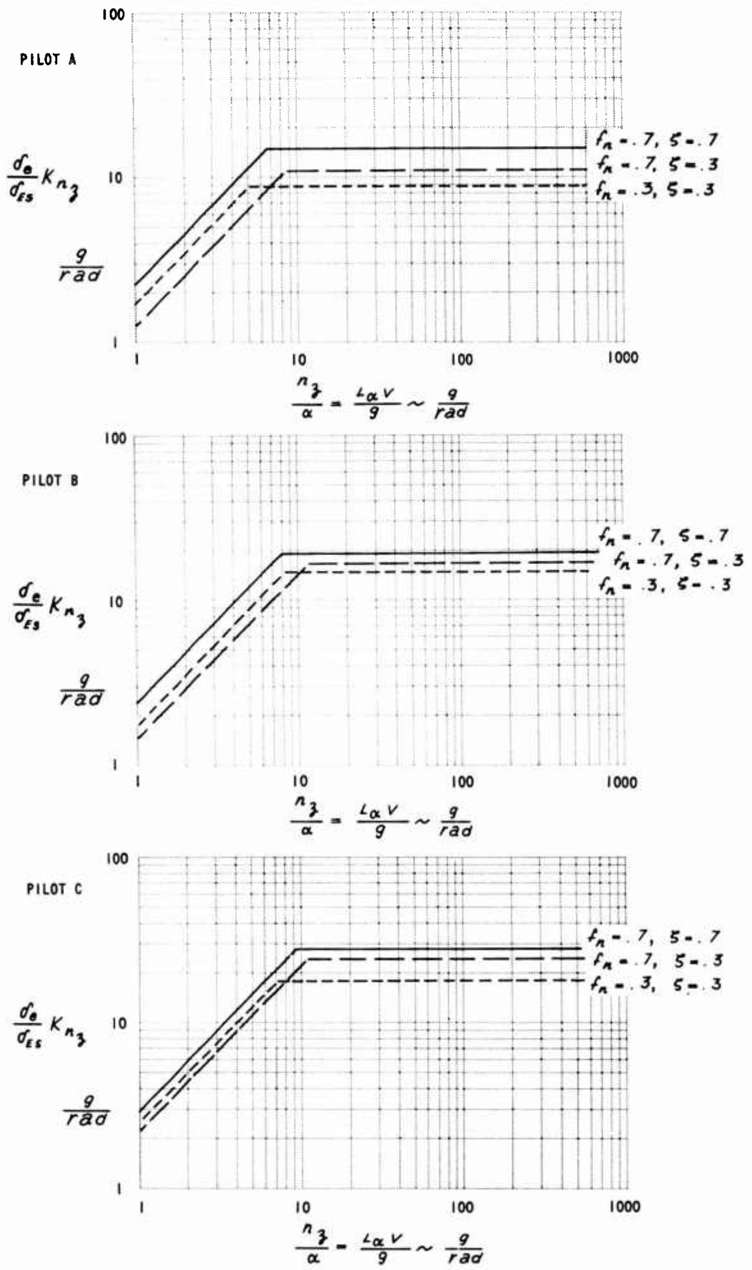


FIGURE 9 VARIATION OF OPTIMUM LONGITUDINAL GAIN WITH SHORT PERIOD DYNAMICS

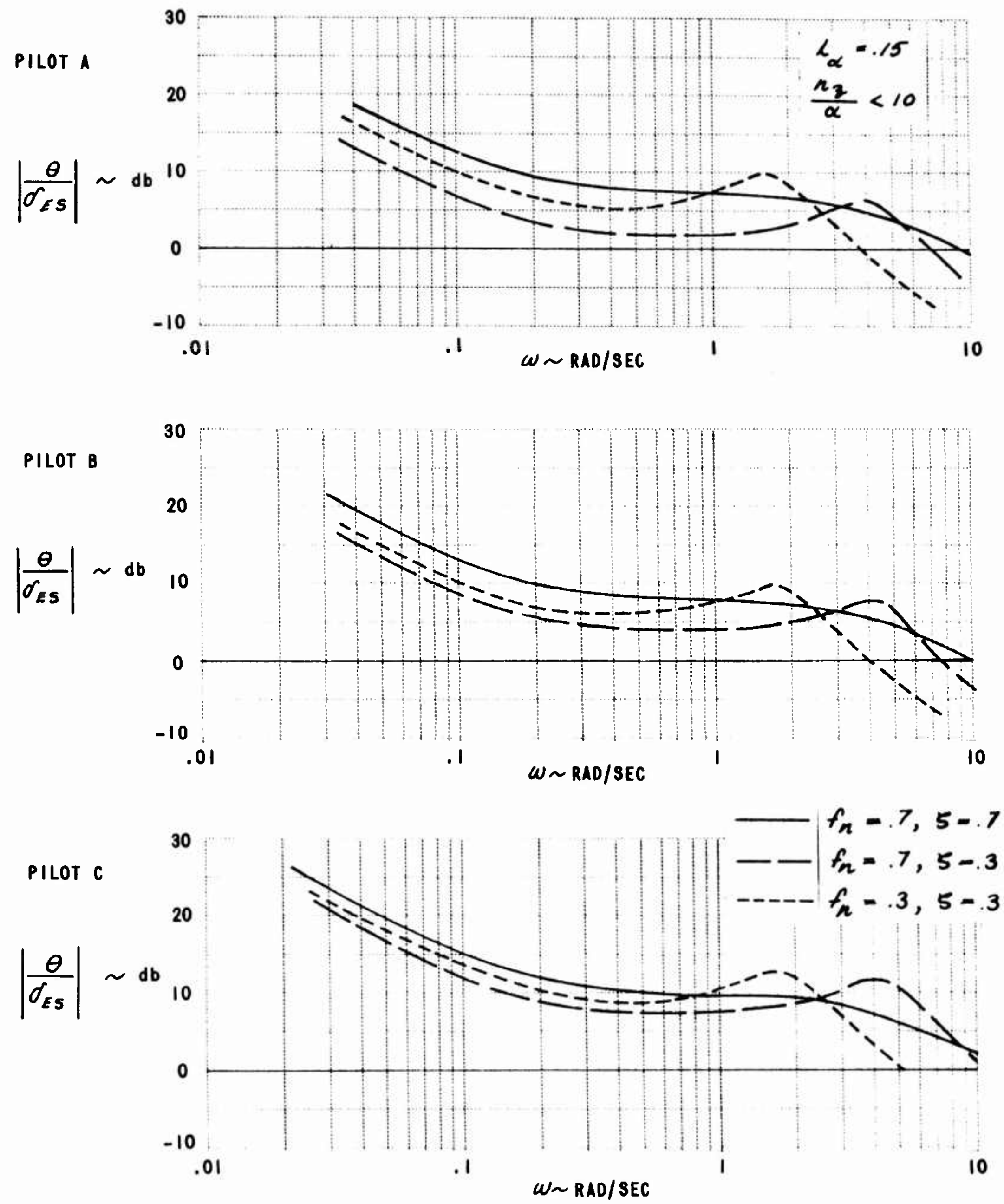


FIGURE 10 COMPARISON OF FREQUENCY RESPONSE FOR θ/δ_{ES} TRANSFER FUNCTION USING AVERAGED GAIN DATA

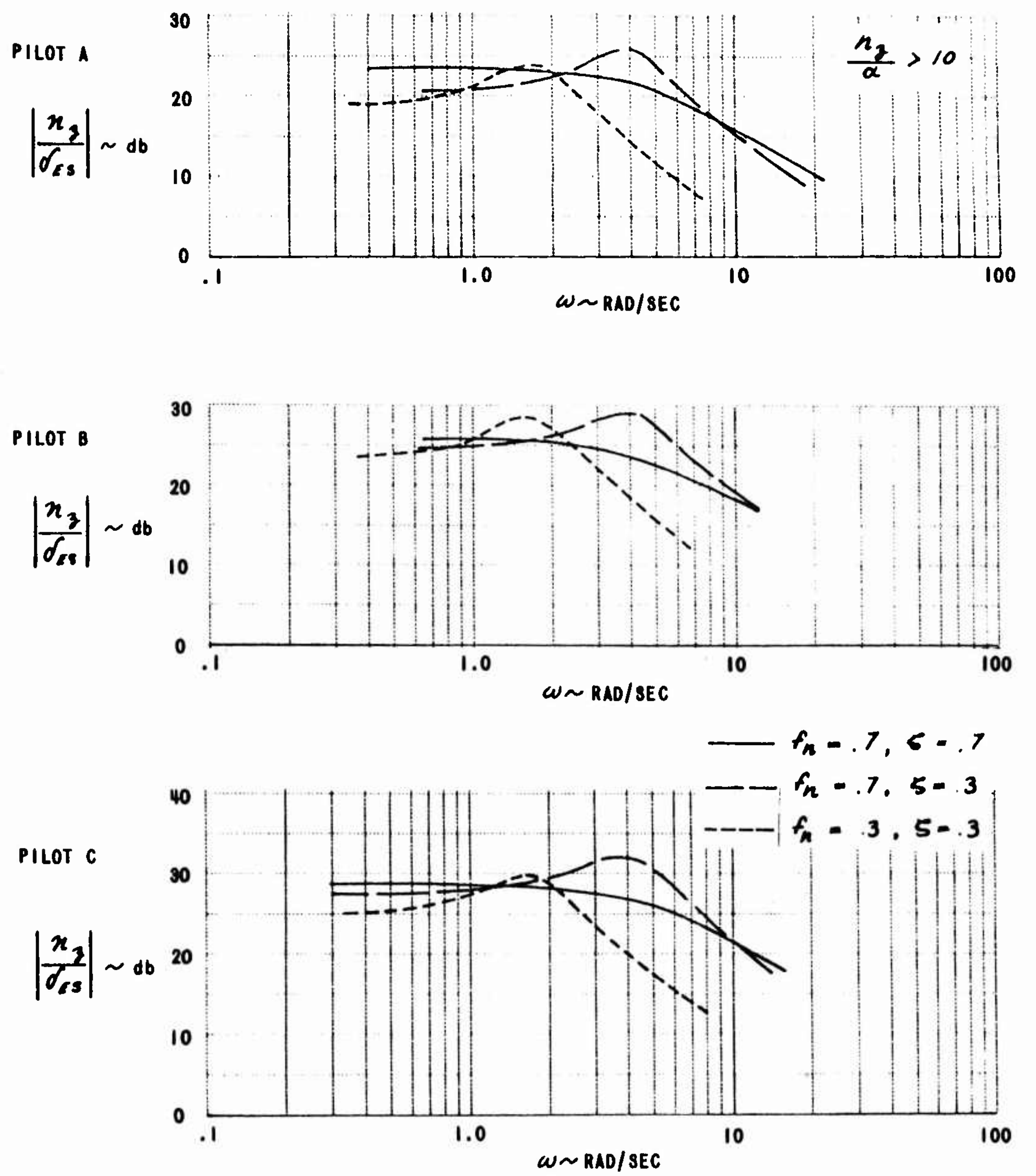


FIGURE 11 COMPARISON OF FREQUENCY RESPONSE FOR n_z/δ_{es} TRANSFER FUNCTION USING AVERAGED GAIN DATA

In the detailed pilot comments the pilots note that the [f_n = .3, ζ = .3] short period configurations are initially slow to respond or have a noticeable lag which the pilot attempts to decrease by over-driving or forcing the response. This comment is not given when the short period frequency is f_n = .7 cps.

These comments and the fact that the three amplitude ratio plots cross in Figure 10 between ω = 2 rad/sec and ω = 3 rad/sec suggest that the stick to elevator gear ratios were chosen on the basis of the actual pitch attitude gain in that frequency band rather than on the basis of the asymptotic approximation to the gain at the short period.

The tendency to overcontrol and to oscillate the airplane when changing attitude is an indication of incipient instability of the pilot-airplane combination. Thus an explanation for the variation in the choice of control gains with short period dynamics which attempts to consider the pilot-airplane combination is attractive. In References 10 and 12 the methods of servo analysis are used to describe the pilot-airplane combination for certain control tasks such as attitude tracking. In these reports, pilot adaption rules, loop closure criteria and a sequence of steps are defined for making a system survey of the pilot-airplane combination. No attempt will be made here to use this technique to explain the variation of optimum $\frac{\delta_e}{\delta_{ES}} \frac{M_\delta}{\omega_n^2}$ with short period frequency and damping ratio. However, the work is referenced and sufficient detail concerning the experimental set-up is provided such that the interested reader may attempt such an analysis if desired.

In Section 4.1.3 it was indicated that when n_z/α is high, the optimum longitudinal gain was selected primarily to get precise normal acceleration control, g-limiting by control feel, and control forces in turns as light as possible. The effect of short period frequency and damping ratio on the optimum steady state normal acceleration gain for high n_z/α is shown in Figure 9. For f_n = .7 cps, all three pilots selected lower steady state normal acceleration gain when the damping ratio was ζ = .3 than when ζ = .7. The lowest gain was selected for the low frequency, low damping ratio [f_n = .3, ζ = .3] short period.

In Figure 11 the amplitude ratio of the n_z/δ_{ES} transfer function is plotted for each short period pole for each pilot using the averaged optimum gain data. From this figure it is seen that the gear ratios selected by each pilot resulted in approximately the same normal acceleration gain for all three short period poles in a limited frequency band between ω = 1 rad/sec and ω = 2.5 rad/sec. Thus it appears that for high n_z/α the stick to elevator gear ratios were chosen on the basis of the actual normal acceleration gain in that frequency band rather than on the basis of the steady state gain at the short period.

The pilots state that they selected the lower normal acceleration gain (and therefore higher stick force per g) for the [f_n = .3, ζ = .3] short period to have more positive g-limiting and also to better resolve their inputs; i.e., with the higher stick force per g, a given stick force would result in a

smaller normal acceleration. This was desirable because the [f_n = .3, ζ = .3] configurations had a significant lag in the normal acceleration response to control which made it difficult for the pilot to estimate the magnitude of the response that would result from the input.

Apparently the pass band of the f_n = .7 configurations was sufficiently high that the response to inputs was essentially in phase with the controller input; the feedback to the pilot was rapid and he did not have to estimate or guess what the response would be. In this situation the pilot has only to use caution in applying smooth control inputs and does not have to predict or estimate what will happen several seconds later.

The cross-over of the average gain curves for [f_n = .7, ζ = .3] and [f_n = .3, ζ = .3] in Figure 9 is thought to be a reflection of the severity of the consequences of an oscillation or an overshoot in the variable that the pilot is attempting to control. When n_z/α is low and the pilot is primarily concerned with pitch attitude, an overshoot is annoying but is not disastrous. When n_z/α is high, positive control of normal acceleration is mandatory to avoid structural damage. Thus the pilots selected a relatively lower gain for the [f_n = .3, ζ = .3] configurations when n_z/α was large.

4.1.5 Variation With Pilot

The difference in pilot preference for optimum longitudinal control gain for each short period is summarized in Figure 12. For high n_z/α pilot A preferred a steady-state normal acceleration gain level approximately one-half that preferred by pilot C. Pilot B's preference was intermediate between that of pilots A and C. Thus pilot A liked stick force per g approximately twice as heavy as pilot C. This result is consistent with past experience with these pilots. Pilot A considered g-limiting by control feel to be of primary importance and so tends to select heavier control forces.

For low n_z/α pilots A and B selected essentially the same average gain level for [f_n = .7, ζ = .7] and [f_n = .3, ζ = .3]. However, pilot C's preference was always appreciably higher than either pilot A's or pilot B's average preferred gain.

4.1.6 Static to Short Period Gain Ratio

In References 10 and 12 another parameter of the pitch attitude transfer function was posed as possibly being significant to handling qualities: the ratio of static gain to gain asymptote at the short period frequency. In Reference 12 it is concluded that values of the ratio less than one should tend to produce low-frequency droop unless the pilot adds equalization of his own in closing the pilot-airframe loop in attitude tracking tasks.

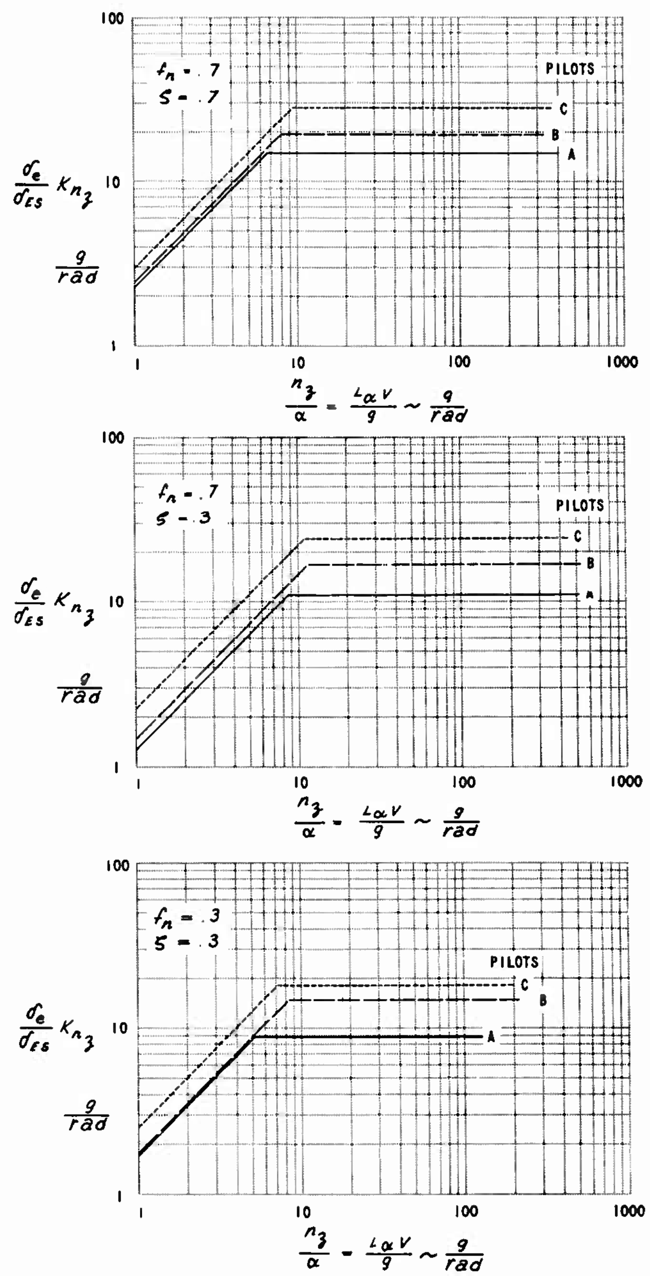


FIGURE 12 VARIATION OF OPTIMUM LONGITUDINAL GAINS WITH PILOT

In terms of transfer function parameters the ratio is given in References 10 and 12 by the following expression

$$\frac{K_{\theta_{STATIC}}}{K_{\theta_{S.P.}}} = \frac{1}{\omega_{n_P}^2 \tau_{\theta_1} \tau_{\theta_2}}$$

This expression applies to situations where the numerator of the θ/δ_e transfer function factors into two real roots and the short period frequency is higher than $1/\tau_{\theta_2}$.

For several of the low L_α configurations (code 024, 121, 122, 124) the θ/δ_e numerator factored into a complex pair. Thus, the "static-to-short period-gain ratio" can be written as follows for these configurations.

$$\frac{K_{\theta_{STATIC}}}{K_{\theta_{S.P.}}} = \frac{\omega_{n_Z}^2}{\omega_{n_P}^2}$$

For the $[f_n = .3,\ \zeta = .3]$ short period configurations with $L_\alpha = 4$ the break point was at a frequency higher than the short period frequency. For these configurations (Code 154, 254, 354, 454) the static to short period gain ratio was calculated using the following expression:

$$\frac{K_{\theta_{STATIC}}}{K_{\theta_{S.P.}}} = \frac{\omega_{n_{S.P.}}}{\omega_{n_P}^2 \tau_{\theta_1}}$$

The computed values of this ratio are tabulated in Table D-3 of Appendix D. The values are plotted in Figure 13 for each short period as a function of $\frac{L_\alpha V}{g}$. This ratio is independent of the stick to elevator gear ratio selected by the pilots.

The value of the gain ratio is dependent in all cases on the magnitude of the phugoid frequency. For $M_u = 0$, the phugoid frequency can be approximated in level flight as follows:

$$\omega_{n_P}^2 = 2\frac{g^2}{V^2}\left(-\frac{M_\alpha}{\omega_{n_{S.P.}}^2}\right)$$

The quantity in parentheses can be written as

$$-\frac{M_\alpha}{\omega_{n_{SP}}^2} = \frac{-M_\alpha}{-M_\alpha - L_\alpha M_q} = \frac{1}{1 + \frac{M_q}{M_\alpha} L_\alpha}$$

Thus the phugoid frequency and therefore the static to short period gain ratio are dependent on the values of M_q and M_α as well as L_α.

Initially the simulator program was set up to use M_q to vary the short period damping ratio; however, for the low frequency, low damping ratio, high L_α configurations it was necessary to use large positive

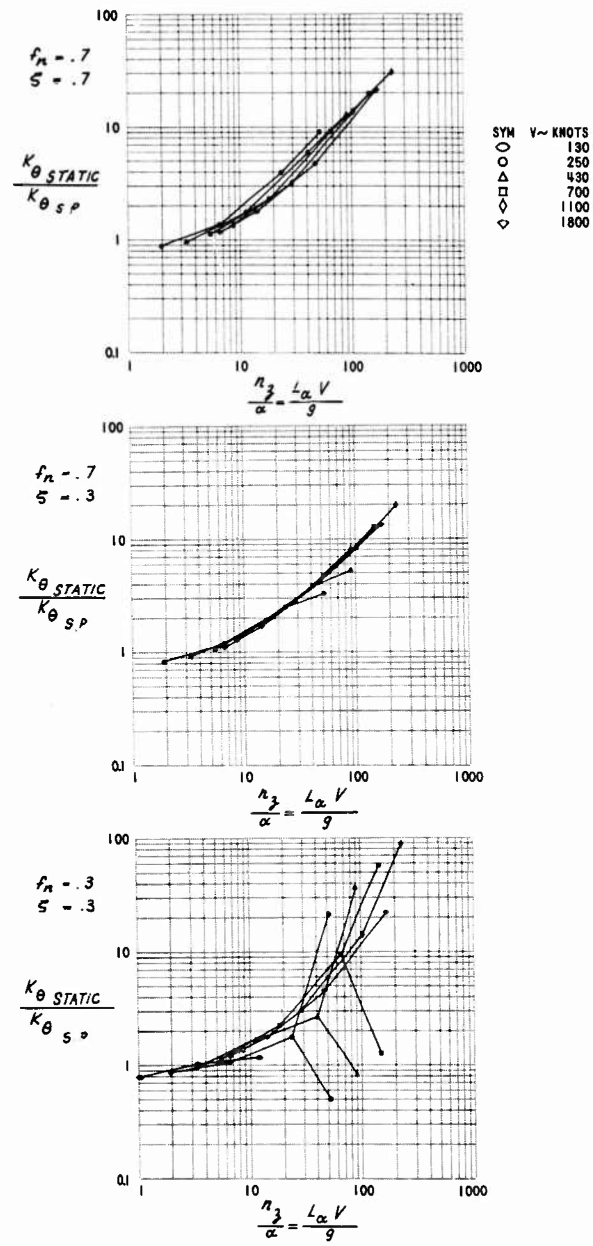


FIGURE 13 STATIC GAIN RELATIVE TO GAIN AT SHORT PERIOD IN PITCH ATTITUDE TRANSFER FUNCTION

values of M_q to obtain the low damping ratio. This of course resulted in peculiar stick force characteristics in turns. (In a steady turn there is a component of $\dot{\psi}$ about the Y axis. For these low frequency high L_α configurations the $M_q q$ term was large and positive and canceled or overshadowed the $M_\alpha \alpha$ term in the pitching moment equation. Thus, the pilot had to hold forward pressure on the stick during steady turns.)

These particular configurations were recalculated using a combination of M_α, M_q and $M_{\dot{\alpha}}$ such that M_α and M_q were always negative and $M_{\dot{\alpha}}$ was made positive where necessary to get the low damping ratio. The effect on the phugoid frequency and therefore on the static-to-short period-gain ratio can be seen in Table D-3 of Appendix D and in Figure 13.

In Figure 13, for the $[f_n = .3,\ \zeta = .3]$ short period, it is seen that the static to short period gain ratio was approximately 45 times as large when $M_{\dot{\alpha}}$ was used instead of M_q to control the short period damping ratio. One of the most interesting results of the re-evaluation of these configurations is that the pilots selected essentially the same elevator gear ratio regardless of whether $M_{\dot{\alpha}}$ or M_q was used to control the damping ratio. This indicates that in smooth air the pilots considered the airframe gain at the short period to be more important than the static pitch attitude gain since their choice of gear ratio resulted in constant "gain at the short period" and widely different static gains.

Examination of the pilot comments for the above described configurations indicates that the pilots' major objection was to the poor normal acceleration control which was caused by the low frequency-low damping ratio of the short period in conjunction with the high L_α, i.e., the short period dynamics result in poor attitude or angle of attack control and the high L_α imposes a severe penalty in the form of a large acceleration response. The configurations using positive M_q had the additional objection of peculiar steady stick forces in turns. It was not possible to attribute any specific comments to the large difference in the static to short period gain ratio or to the fact that this ratio was less than unity for some of these configurations.

In Figure 13 it is seen that the static-to-short period-gain ratio was slightly less than unity when $\frac{L_\alpha V}{g}$ was less than about 3.5 g/rad. Although these configurations were rated unsatisfactory, the rating was based on the poor flight path control and the restriction on bank angle rather than any difficulty in attitude control. Thus, although the rating degradation correlates with values of static to short period gain ratios of less than unity, the pilot comments indicate that the cause of the rating degradation was due to other difficulties than attitude control.

4.2 PILOT RATING DATA

4.2.1 Effect of L_α and V

Time histories of normal acceleration, angle of attack, pitch attitude, pitch rate, and incremental velocity are plotted in Figure 14 a for seven combinations of L_α and V for the $[f_n = .7$ and $\zeta = .7]$ short period pole. The time histories represent the response of each configuration to a two-degree side controller step input. The stick to elevator gear ratio used for each configuration is based on the averaged longitudinal gain data of pilot B (see discussion of Section 4.1.2 and Figure 8b). Time histories for the $[f_n = .7, \ \zeta = .3]$ and the $[f_n = .3, \ \zeta = .3]$ short period poles are plotted in Figures 14 b and 14c, respectively. The individual and combined effects of L_α, V, f_n and ζ on the relative magnitude and phase of the vehicle responses can be seen through detailed examination of the plotted responses in Figure 14a, 14b and 14c together with the approximate expressions C-24 through C-30 of Appendix C.

The relation between normal acceleration and angle of attack expressed by Equation C-28,

$$\frac{n_z}{\alpha} = \frac{L_\alpha V}{g}$$

can be seen by comparing configurations C, D, and E of Figures 14a, 14b or 14c. For high L_α and high V (Configuration C) the acceleration response is large for a very small angle of attack change, while for low L_α and low V (Configuration E) the acceleration response is small for a large angle of attack change. Thus large accelerations result from very small pitch attitude changes when n_z/α is large (Configuration C).

The large angle of attack changes required to maneuver when n_z/α is low are accompanied by large drag changes which result in relatively large speed changes. This situation is illustrated by the responses of Configurations E, D, and C.

The relation between pitch rate and normal acceleration is expressed by Equation C-24 and the relation between pitch rate and angle of attack is expressed by Equation C-26. For correlation with the time histories, however, the reciprocals of Equations C-24 and C-26 are used:

$$\frac{\dot{\theta}/\delta}{n_z/\delta} = \frac{g}{V}\left(\frac{1}{L_\alpha} s + 1\right)$$

$$\frac{\dot{\theta}/\delta}{\alpha/\delta} = L_\alpha\left(\frac{1}{L_\alpha} s + 1\right)$$

In response to an elevator step input, both n_z and α change steady state. The form of the transient is typically second-order with characteristics determined by the short period dynamics. The pitch rate response, however, starts with an initial slope and leads both n_z and α during the short period transient. The time constant of the lead term is approximately $1/L_\alpha$.

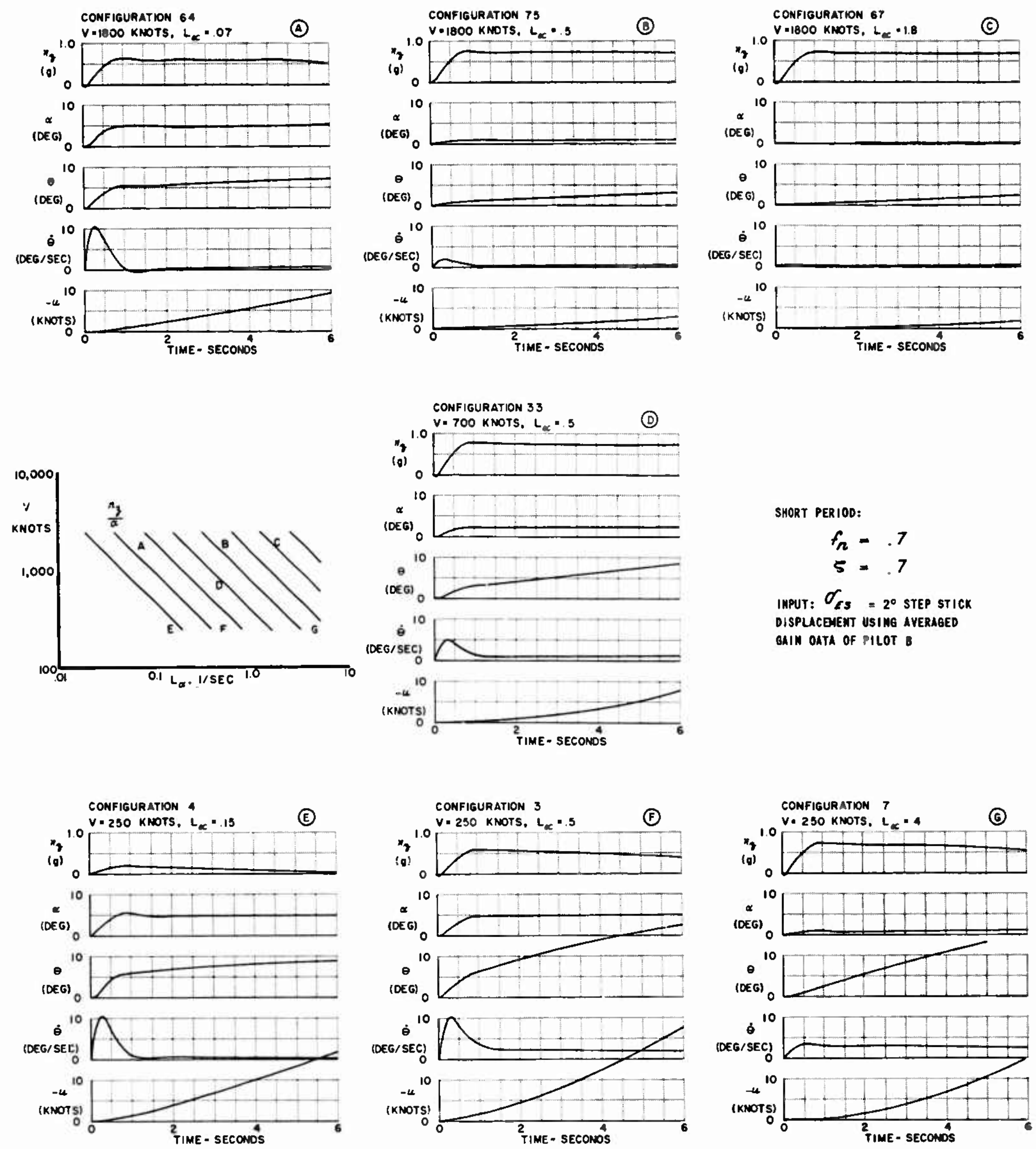


FIGURE 14a LONGITUDINAL RESPONSE TO 2° ELEVATOR STICK STEP INPUT, f_n = .7, ζ = .7

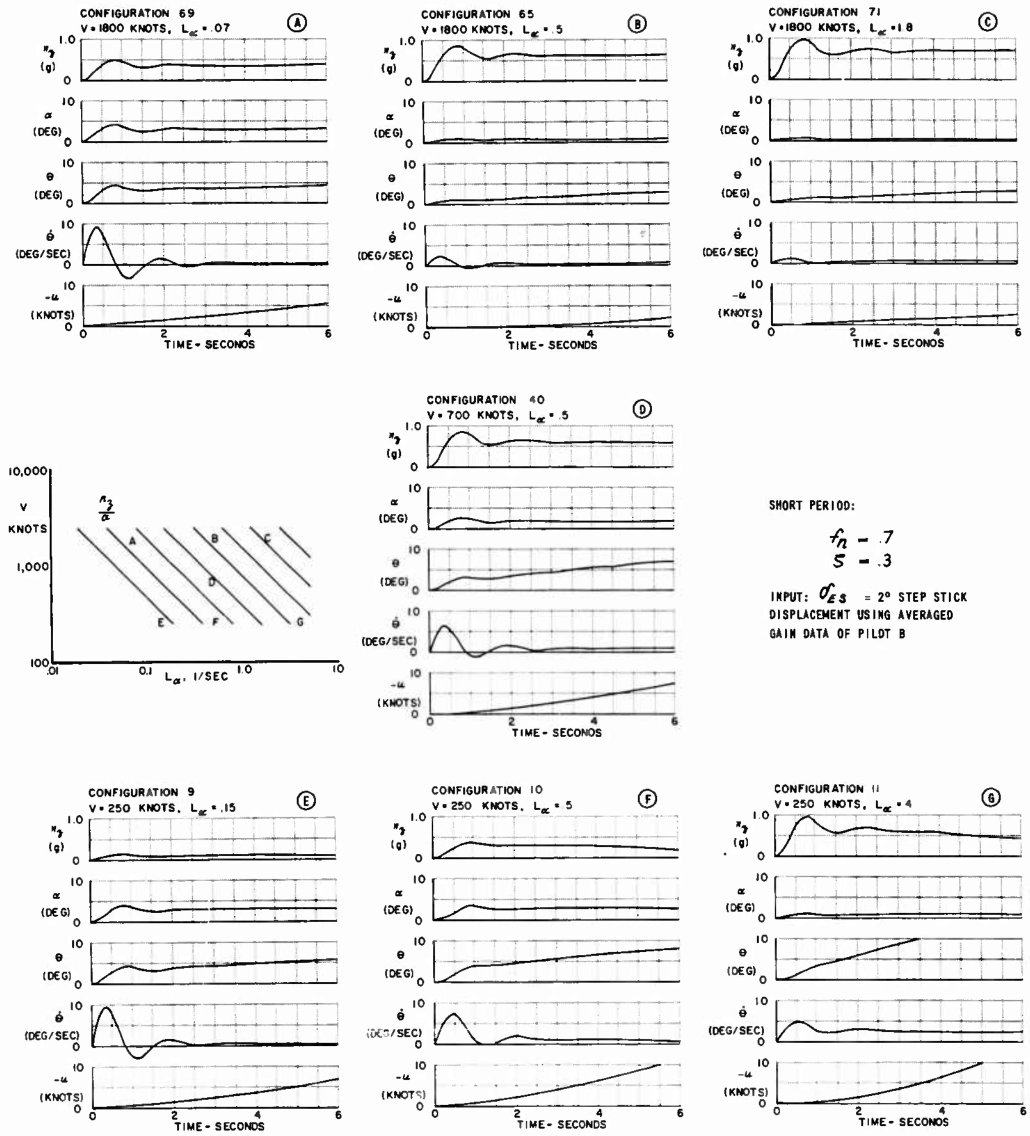


FIGURE 14b LONGITUDINAL RESPONSE TO 2° ELEVATOR STICK STEP INPUT, f_n = .7, ζ = .3

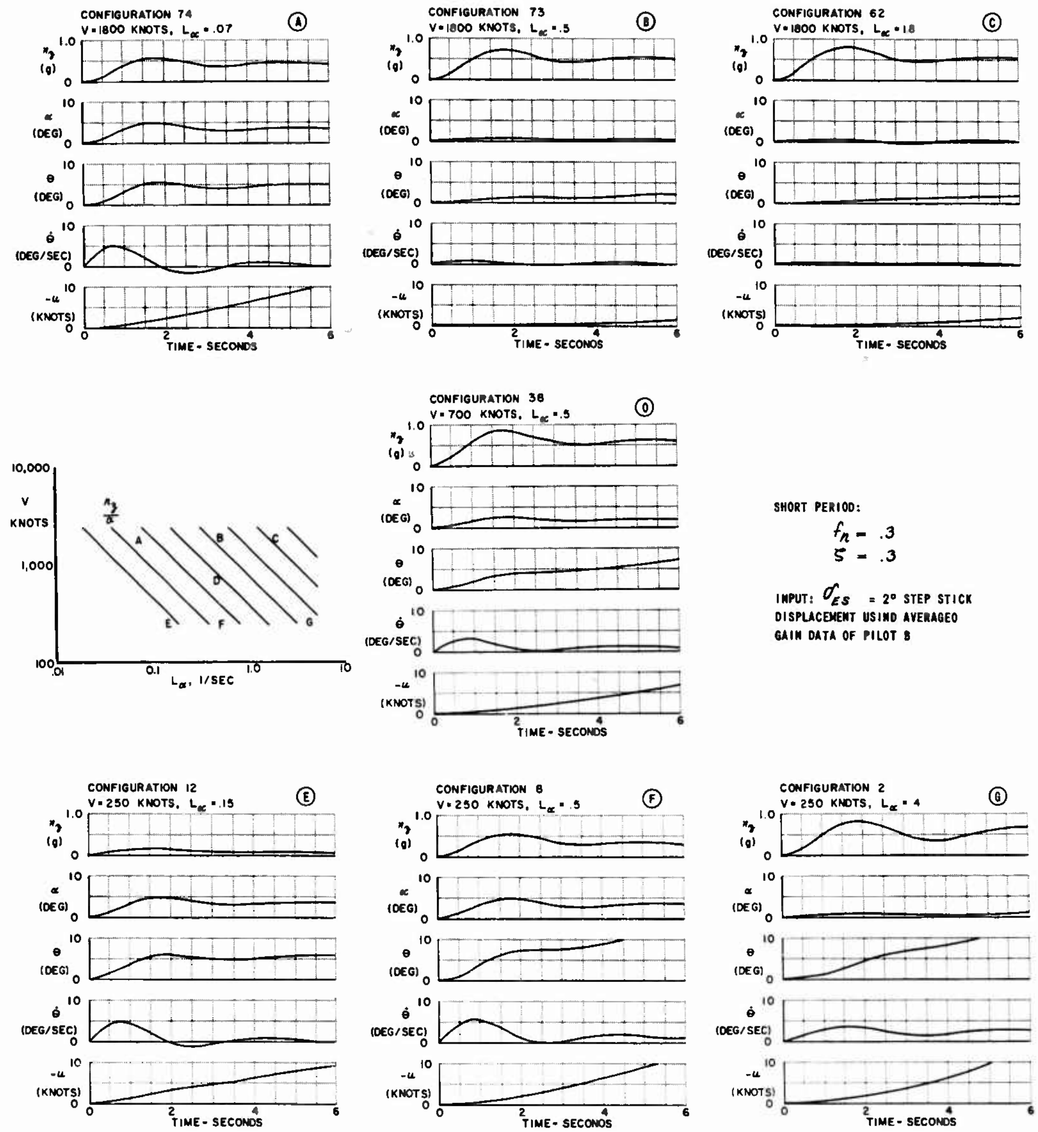


FIGURE 14c LONGITUDINAL RESPONSE TO 2° ELEVATOR STICK STEP INPUT, f_n = .3, ζ = .3

This aspect of the transient motion is illustrated by the responses of Configurations A, B and C or Configurations E, F and G of Figures 14a, 14b and 14c. It is seen that low L_{α} implies a high peak $\dot{\theta}$, while at high L_{α} the peak is much lower.

The steady state pitch rate resulting from an elevator step is related to the steady state normal acceleration by g/V as illustrated by the responses of Configurations B, D and F. For a given normal acceleration the higher the velocity, the smaller the steady state pitch rate will be.

The steady state angle of attack corresponding to a given steady pitch rate is proportional to $1/L_{\alpha}$. This relation is illustrated by the responses of Configurations A, B and C. The steady pitch rate is equal for these three configurations and the steady state angle of attack is seen to be inversely proportional to the value of L_{α} for each configuration.

Although Configurations A and F have greatly different values of V and L_{α} they have the same value of n_{z}/α. The normal acceleration and angle of attack responses of these two configurations are nearly identical; however, the pitch attitude and pitch rate responses are significantly different. The maximum pitch rate which occurs during the transient is nearly equal for the two cases. However, because of the higher velocity of Configuration A the steady pitch rate is considerably lower than that of Configuration F.

It should be noted that the maximum pitch rate of Configuration F occurs at a slightly later time than that of Configuration A. In servo terminology this is because of the phase contribution of the numerator term in the pitch rate to elevator transfer function. The difference in the time at which the maximum pitch rate occurs can also be explained in somewhat different terms by looking at the equations

$$\dot{\theta} = \dot{\alpha} + \dot{\gamma} \qquad \dot{\gamma} = \frac{g}{V} n_{z}$$

$$\dot{\theta} = \dot{\alpha} + \frac{g}{V} n_{z}$$

Although the $\dot{\alpha}$ and n_{z} responses of Configuration A are nearly identical to those of Configuration F, because of the difference in true speed, these quantities are added in different ratio with the result that the maximum pitch rate occurs at a different time.

Configuration F exhibits a larger change in velocity following the step input than does Configuration A. Although the angle of attack and thus the drag time histories are the same for these two configurations, because of the larger pitch angle of Configuration F the gravity component along the longitudinal axis is larger, causing the larger change in velocity.

The effects of short period frequency and damping ratio on the time histories of normal acceleration, angle of attack, and pitch attitude can be observed by comparing responses in Figures 14a, 14b and 14c.

The character of the pitch attitude time history for various combinations of f_n, ζ, L_α and V is of particular interest since this is perhaps the primary response (although not to the point of excluding all other responses) displayed to and sensed by the pilot. Also, it has the most complicated transfer function in the short period approximations.

When the short period damping ratio is high, as in Figure 14a, the pitch attitude response to an elevator step is comparatively straightforward in that it can be approximated by an initial lag and two ramps of different slope. However, when the short period damping ratio is low, as in Figures 14b and 14c, the pitch attitude response appears considerably more complicated: it exhibits changes in slope, hesitations and even reversals of direction which complicate the pilot's task of deciding how much control to apply and when it should be applied. This situation is magnified to some extent when the short period frequency is low because of the longer initial delay and the longer hesitation (or the longer time during which the slope is reversed) following the initial rotation.

In the preceding paragraphs the reader's attention was directed to the various aspects of the response of the open-loop or uncontrolled airplane to elevator stick inputs. Brief descriptions of some of the effects of f_n, ζ, L_α and V on the relative magnitude and phase relation of the various responses were given. In the following paragraphs the relative importance of the various aspects of the airplane's responses will be indicated by the pilot ratings obtained.

In Figure 15 the smooth air ratings and the rough air (rms gust velocity = 6.5 ft/sec; probability of encountering this or greater turbulence at low altitude is 5% from Reference 2) ratings of each configuration by each pilot are listed for each short period pole or grids of L_α and V. Logarithmic scales are used to provide uniform spacing of the test points in this figure. The combinations of L_α and V tested are designated by x's in Figure 15 and the pilot ratings are listed in a triangular array about each x. Pilot A's ratings are tabulated about each x, Pilot B's ratings at the lower right, and Pilot C's ratings at the lower left of each x.

In Figure 16, over-all average ratings for each test configuration are listed. These average ratings were obtained by first averaging the ratings for each pilot when more than one were available and then averaging the individual pilot averages. The averaged rating data of Figure 16 are interpreted by means of shading. Areas of the L_α - V grid have been shaded light, medium or dark in accordance with the three general categories of the rating scale.

Shade	Average Rating Range	Description
Light	1 - 3.5	Acceptable and Satisfactory
Medium	3.6 - 6.5	Acceptable but Unsatisfactory
Dark	6.6 - 10	Unacceptable

The shading of areas between data points is based on engineering judgment and detailed familiarity with the pilot comment data.

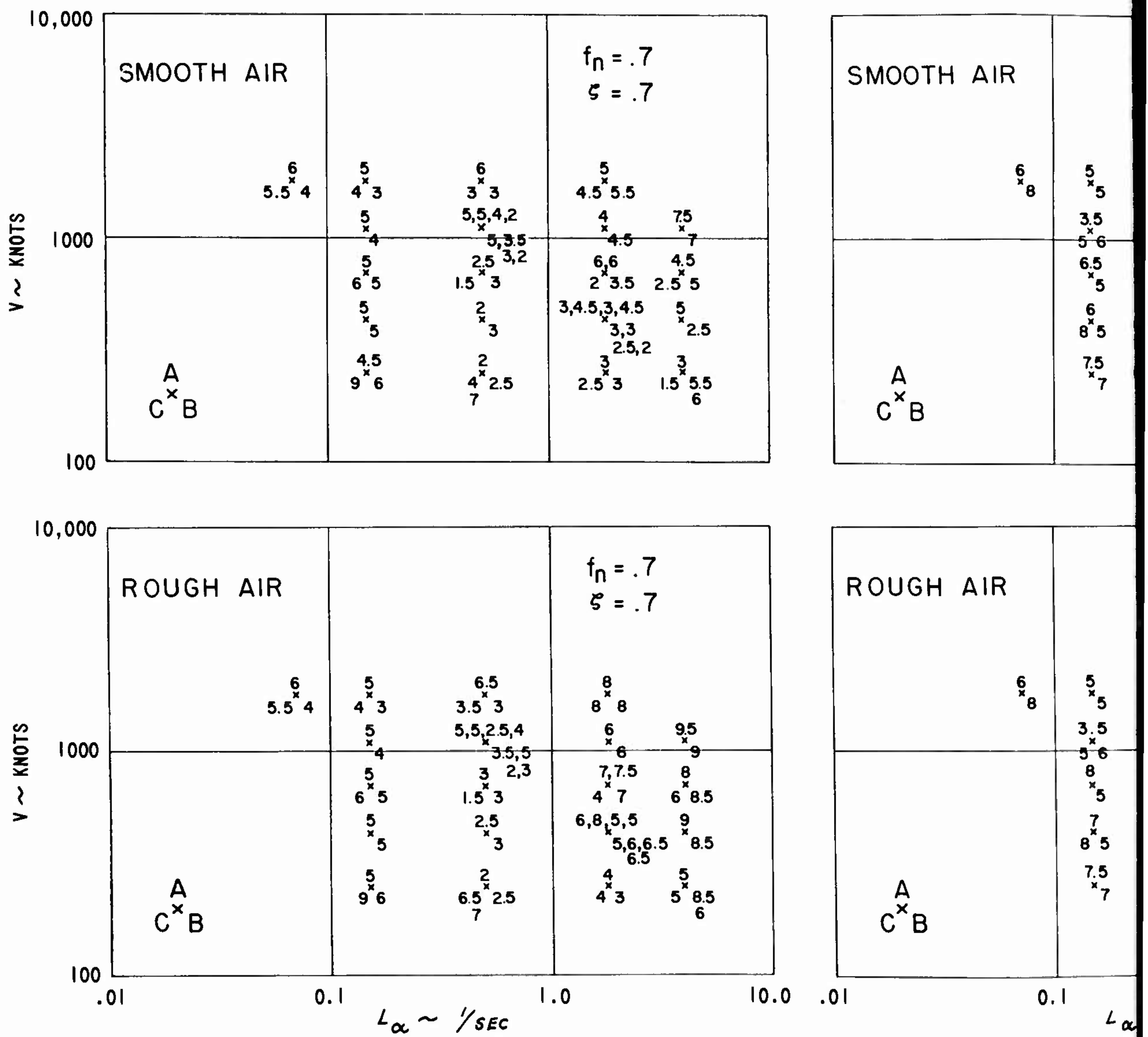


FIGURE 15 INDIVIDUAL

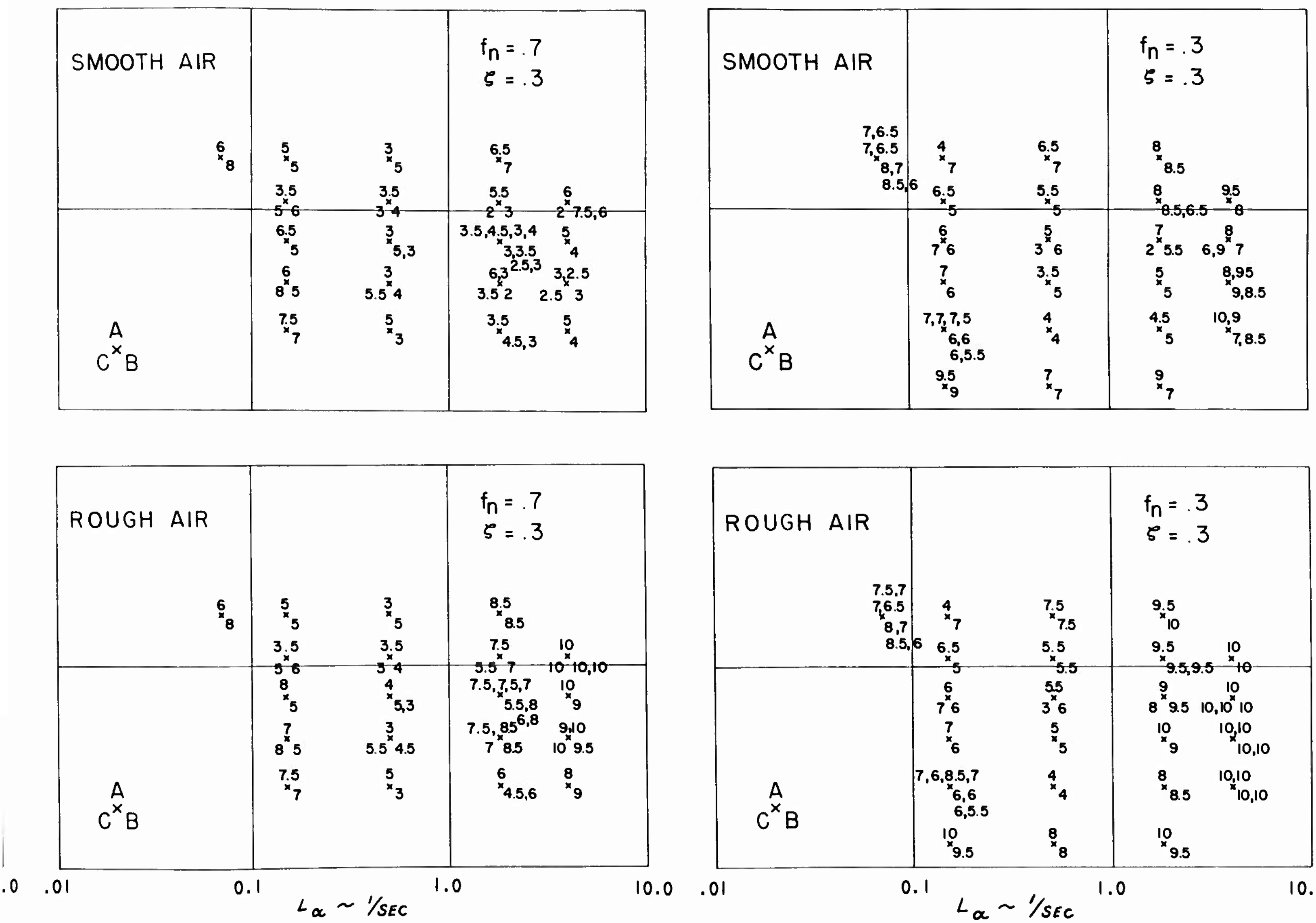
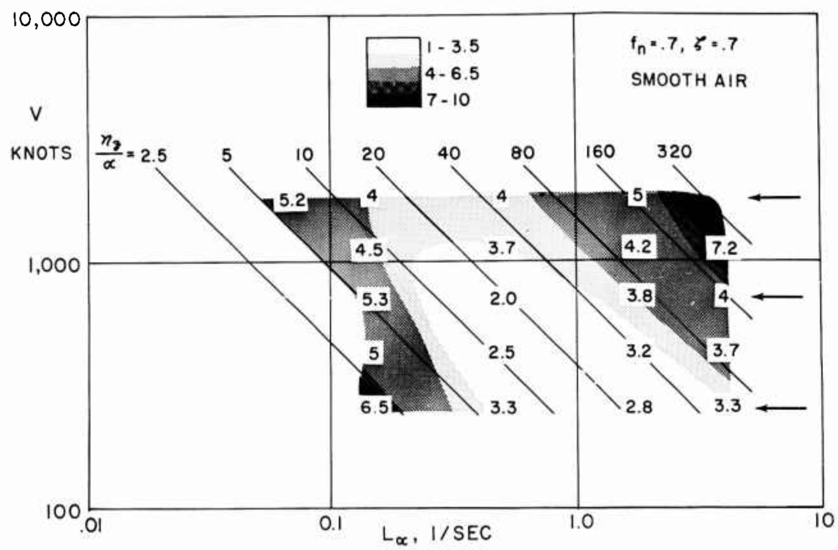
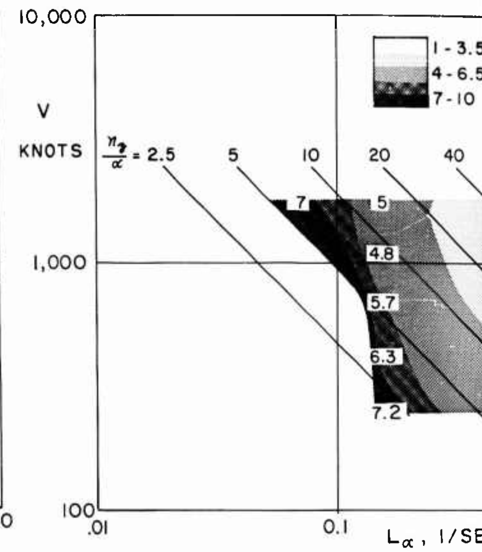
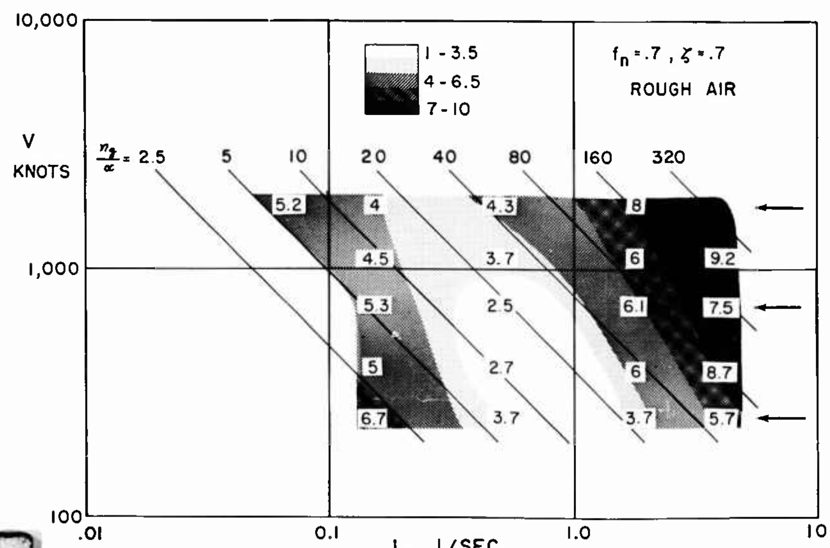


FIGURE 15 INDIVIDUAL PILOT RATING DATA





NOTE: ARROWS INDICATE CONFIGURATIONS EVALUATED BY F



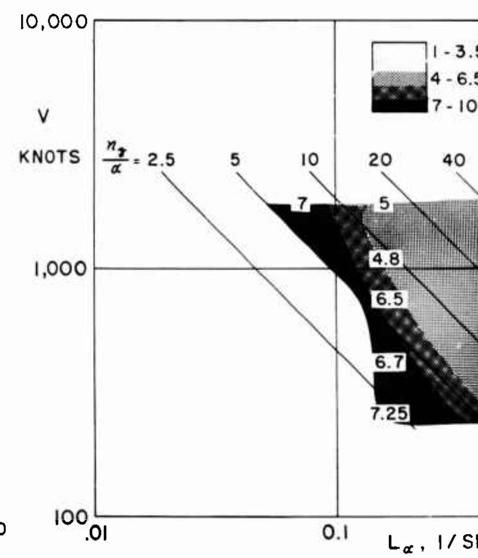
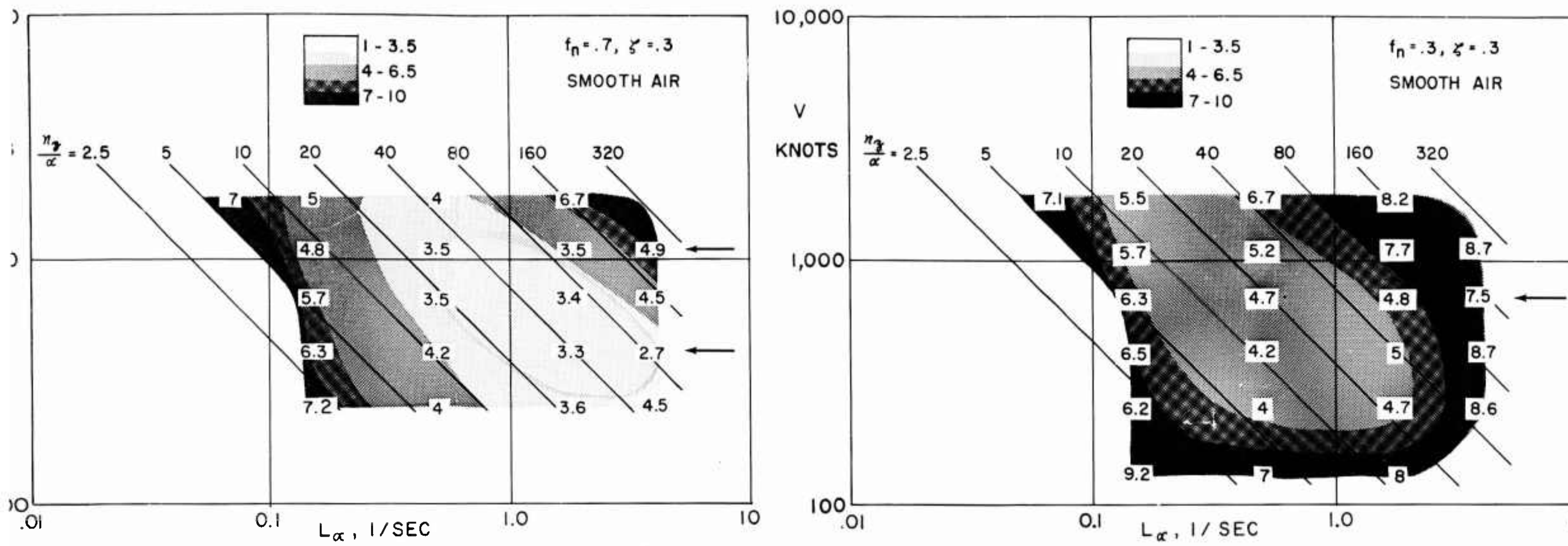


FIGURE 16 AVERAGED PI



IONS EVALUATED BY PILOT C

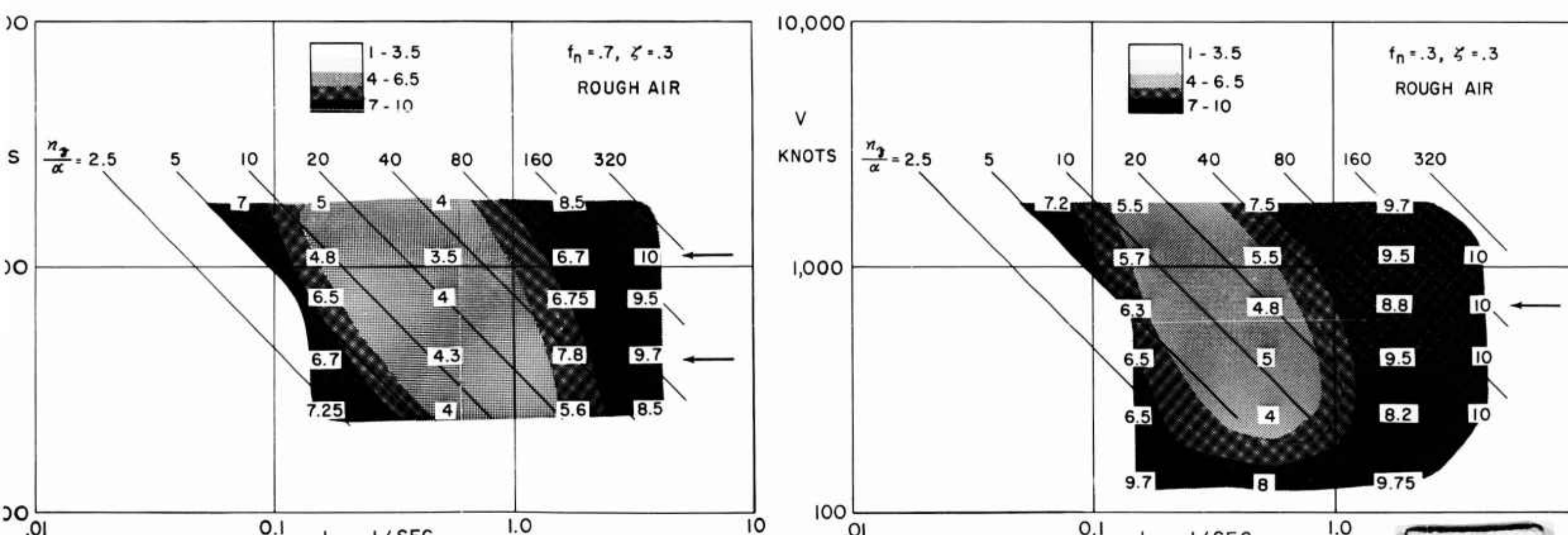


FIGURE 16 AVERAGED PILOT RATING DATA

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The arrows at the right of the diagrams of Figure 16 identify the velocities which were done by Pilot C, thus, the average ratings in these rows include the ratings of all three pilots.

Superimposed on Figure 16 are lines of constant $n_z/\alpha = L_\alpha V/g$.

The smooth air data of Figures 15 and 16 indicate that pilot acceptance of longitudinal flying qualities is a function of the parameter $n_z/\alpha = L_\alpha V/g$. In smooth air for all three short period poles, the most satisfactory pilot ratings were obtained for 5 g/rad $< n_z/\alpha <$ 80 g/rad. Unacceptable ratings were obtained mainly at the extreme combinations of L_α and V examined, i.e., at the very high or very low values of n_z/α .

The unacceptable ratings in these areas are related to the magnitude of the angle of attack change required to maneuver the airplane. When n_z/α is very low, extremely large changes in angle of attack must be made to develop the incremental lift force required to maneuver the airplane. There are a number of consequences which result from this large angle of attack change:

a. Large drag changes occur, thus throttle coordination is required if airspeed is to be maintained.

b. For abrupt elevator inputs, the initial pitch rate associated with the rotation about the c.g. may be quite large compared to the steady pitch rate resulting from the flight path curvature.

c. The maximum allowable angle of attack produces only small normal accelerations. Therefore:

   1. The bank angle must be restricted to maintain level flight.

   2. Large attitude changes are required when rolling into and out of turns.

   3. For maneuvers the airplane must be rotated through a large angle to develop a small normal acceleration. This attitude must be held for considerable time until the small normal acceleration integrates into a flight path change. During this time the pilot tends to lose correspondence between the airplane's pitch attitude and its flight path.

When n_z/α is very large, extremely small changes in angle of attack will produce very large changes in the lift force. The following consequences result from this situation:

a. The airplane can be flown and maneuvered with fixed throttle since the angle of attack changes required to maneuver are small and thus the drag is nearly constant.

b. Control of rate of climb is quite difficult. Large rates of climb occur for no change in power and very small changes in pitch attitude.

c. Control of normal acceleration is a problem. Caution is required in maneuvers to prevent exceeding the structural limits of the airframe.

For a given value of n_z/α, the pilots tended to rate the flying qualities of the very high velocity configurations somewhat less satisfactory than they did the intermediate and low velocity configurations. There are several reasons for the less satisfactory average ratings obtained at the higher velocity.

Consider first the low n_z/α situation. For a given n_z/α the value of L_α is lower for the high velocity configurations. Therefore (see discussion of configurations A and F of Figure 14) the initial pitch rate overshoots the final pitch rate considerably more for the high velocity configurations. That is, the initial pitch response as the airplane rotates about its c. g. may be quite rapid compared to the pitch change resulting from flight path curvature if the short period frequency is high. The longitudinal control gain selected in this region of n_z/α is a compromise between the initial pitch attitude response and the steady forces in turns. The requirement for light stick forces in turns results in high attitude gain. The pilot therefore tends to have difficulty in maintaining precise attitude control and this contributes to the rating degradation.

Another factor that contributes to the rating degradation at high velocity and low n_z/α is the fact that a given rate of turn requires a larger bank angle when the velocity is high. Thus, the angle of attack, or equivalent bank angle, limitation imposed on the configuration by the low n_z/α becomes more objectionable to the pilot at the high velocity.

Consider next the high n_z/α situation. When n_z/α is large the angle of attack change required to maneuver is small and thus the initial pitch change due to rotation about the c. g. is small. Also, when the velocity is high the steady state pitch rate is small for a given normal acceleration. These two factors combine when n_z/α and V are both large. The result is that the airplane can be maneuvered throughout its normal acceleration envelope with very small pitch attitude changes. The pilots found that the attitude indicator was not adequate for the flight control task in this situation. That is, nearly undetectable changes in the attitude display corresponded to quite large normal acceleration and rate of climb responses. This, of course made the flight control task more difficult simply because one of the primary instruments that the pilots

normally used no longer provided usable information.

Another aspect of flight control at very high velocity is expressed by the following equation:

$$\dot{h} = V \sin \gamma$$

Consider nonmaneuvering flight near trim conditions. In this case angle of attack can be considered constant and very small; thus $\Delta\Theta \approx \Delta\gamma$. Because of the very large velocity, small changes in flight path angle or pitch angle will result in large changes in rate of climb. Thus in attempting to hold constant altitude or zero rate of climb, the pilot must control pitch attitude to extremely small tolerance. In many cases the pilots found the attitude display inadequate for this task and attempted to use the rate of climb display instead.

It should be noted that the situation just discussed is a function of true speed and steady state attitude and thus applies regardless of n_z/α or L_α. However, the following dynamic relation should also be considered,

$$\frac{\dot{h}(s)}{\delta(s)} = \frac{V\Theta(s)/\delta(s)}{\left(1/L_\alpha\, s+1\right)}$$

When L_α is large the rate of climb response to attitude changes is immediate, however, when $L_\alpha < .2$ for example, it takes more than five seconds for the rate of climb to reach 63% of its final value following a step attitude change. This lag in the airplane's rate of climb response to pitch attitude changes tends to reduce the pilot's difficulty in maintaining constant altitude. He is, however, flying the airplane in a transient condition and this may manifest itself as an apparent phugoid oscillation in altitude.

The ratings obtained at V = 130 knots for the $[f_n = .3,\ \zeta = .3]$ short period are all in the unacceptable classification. These ratings do not seem unreasonable for the $L_\alpha = .15$ and $L_\alpha = .5$ configurations since n_z/α is quite low. However, the unacceptable ratings for the $L_\alpha = 1.8$ configuration do not seem to be consistent with the more acceptable ratings obtained at the same value of n_z/α but higher velocity. The rating of 9 given by pilot A for this configuration was based on the difficulty in controlling airspeed and the tendency for the pilot-airplane combination to develop a long period pitching oscillation. It should be noted that the phugoid frequency for this configuration was of the order of 1/8 of the short period frequency and that the phugoid damping ratio was slightly negative, $\zeta_p \cong -.01$. Also, the value of L_α was nearly equal to the short period frequency expressed in rad/sec; $L_\alpha = 1.8$ 1/sec, $\omega_n = 1.88$ 1/sec. All three of these factors have been suggested as potential sources of control difficulty for attitude tracking tasks in Reference 10. Whether or not any one of the factors or the combination was the cause of the unacceptable ratings cannot be definitely established.

4.2.2 Effect of Short Period Dynamics

The experiment was designed such that information was obtained at two short period frequencies with constant damping ratio and at two damping ratios with constant frequency. Thus some indication of the interactions of f_n, ζ, V and L_α can be obtained by comparing ratings for different frequencies at constant damping ratio or by comparing ratings for different damping ratios at constant short period frequency.

The three short period poles selected for use in the ground simulator program were ranked by the pilots, in the flight tests of Reference 4, in the following order of preference.

Order of Preference	Short Period Pole f_n	ζ
1	.7	.7
2	.7	.3
3	.3	.3

The data of Reference 4 were taken at a nominal flight condition of V = 440 knots and L_α = 1.9.

Comparison of the simulator results for the three short period poles for V = 430 knots and L_α = 1.8 also indicates a pilot preference for [f_n = .7 cps, ζ = .7] over either of the other two short period poles. The difference in average rating between [f_n = .7, ζ = .7] and [f_n = .7, ζ = .3] is, however, very slight for this particular combination of V and L_α.

The differences between average ratings for [f_n = .7, ζ = .3] and [f_n = .3, ζ = .3] are tabulated on the L_α - V grid in Figure 17. The fact that all of the differences are either zero or negative clearly indicates that, for ζ = .3, the lower-frequency short period, f_n = .3 cps, is less acceptable than the higher-frequency short period, f_n = .7. Below $n_z/\alpha \approx 15$ g/rad in Figure 17 the differences between ratings are all less than one rating unit, while above $n_z/\alpha \approx 15$ g/rad the differences between ratings are significantly larger. This systematic variation of the rating differences with n_z/α is thought to be due to the following factors:

> When n_z/α is large, the pilot must have precise control of normal acceleration to avoid exceeding structural limits. In this situation the relatively long lag of the low frequency short period, f_n = .3 cps, becomes objectionable and results in less satisfactory pilot ratings due to the poor positive control.
>
> When n_z/α is low, large changes in angle of attack and pitch attitude are required to maneuver resulting in large initial pitch rates. This objectionable

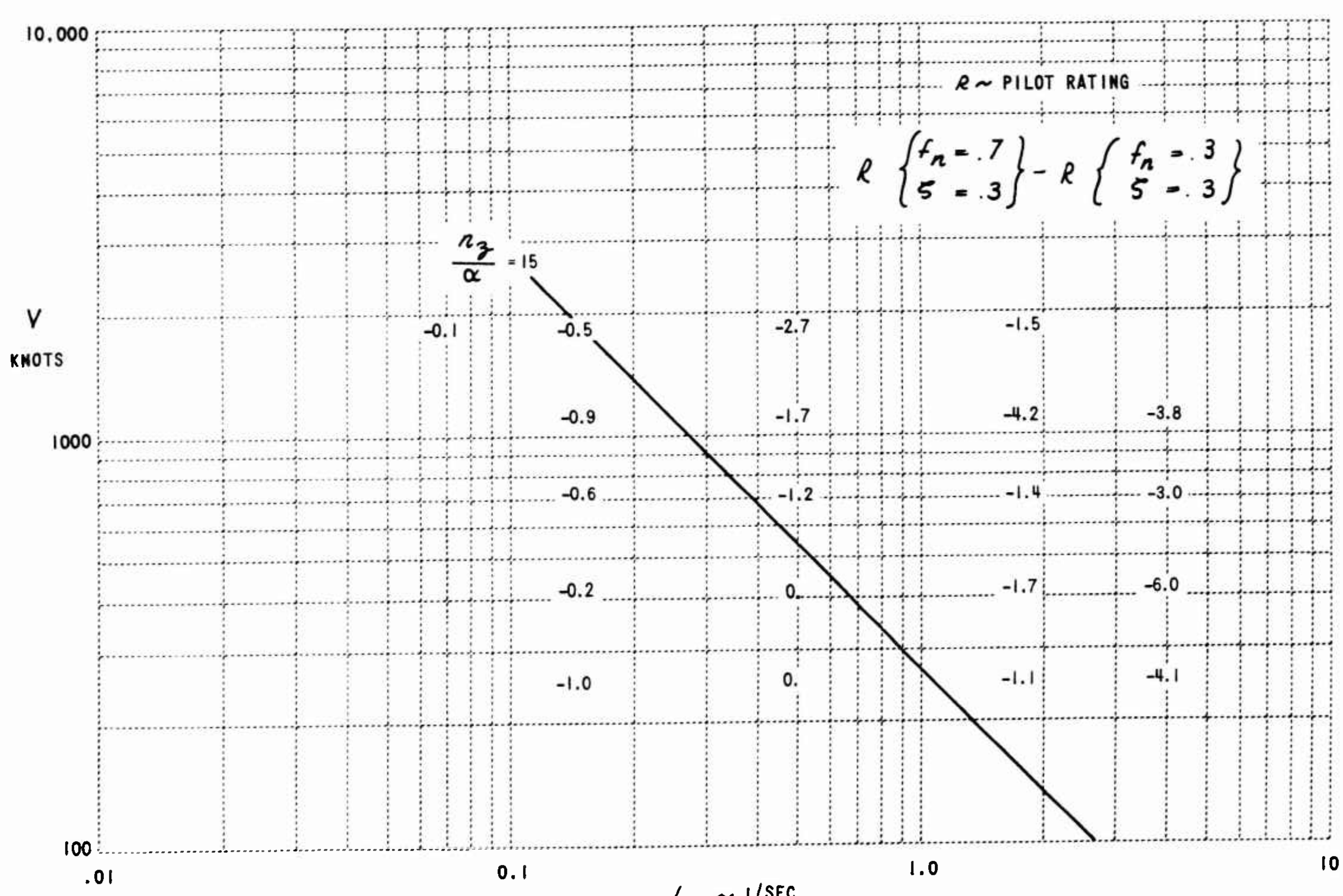


FIGURE 17 COMPARISON OF PILOT RATINGS FOR CONSTANT DAMPING RATIO

situation is ameliorated for the lower short period frequency.

The differences between average ratings for [f_n = .7, ζ = .7] and [f_n = .7, ζ = .3] are tabulated on the L_α - V grid in Figure 18. For n_z/α < 30 g/rad the differences between ratings are all negative indicating a preference for the higher damping ratio at f_n = .7. The higher damping ratio results in a lower initial pitch rate and eliminates the tendency for the pitch rate to reverse sign during the transient. Both of these factors tend to improve the pilot rating. For n_z/α > 30 g/rad in Figure 18 the rating differences are inconsistent and vary from -1.7 to + 2.3 rating units. The control task used in the evaluations did not require precise attitude tracking, so the moderately low damping ratio did not cause objections. Also, since the tests were done in a fixed-base simulator, the normal acceleration oscillations were not felt by the pilot. These factors tend to reduce the expected rating differences for the two damping ratios. The variations in the differences of the average ratings which are listed in Figure 18 are caused in the main by intra-and-inter-pilot rating variations rather than by the difference in short period damping ratio. The number of ratings for each configuration by each pilot is small, so the averages are strongly influenced by single ratings.

4.2.3 Effect of Rough Air

The individual pilot ratings for smooth air and rough air are listed on Figure 15 and the averaged pilot ratings are listed on the shaded diagrams of Figure 16. The degradation in pilot ratings from smooth air to rough air is graphically illustrated by the diagrams of Figure 16. These experimental results confirm the analysis of Section 2.4 and illustrate the relative importance of L_α , f_n , ζ and V in determining the response to turbulence.

The pilot comment data indicate that the rough air ratings were based on whether or not the turbulence caused any control difficulties and on the pilot's estimation of the severity of the ride he would experience.

The most severe rating degradations occurred for the highest L_α values and for the low frequency, low damping ratio configurations. The reduction in normal acceleration response at the c. g., which occurs for higher short period frequency and damping ratio is reflected in the pilot ratings of Figure 16. The smallest rating differences were obtained for the short period pole [f_n = .7, ζ = .7].

The effect of true speed is to shift the power spectrum of the turbulence to higher frequency (See Figure A-4) where the airplane's normal acceleration response is higher (see Figure 5). This effect is reflected by the large rating differences for the higher velocities. The pilots also noted the increase in the frequency of the normal acceleration fluctuations at the higher velocities.

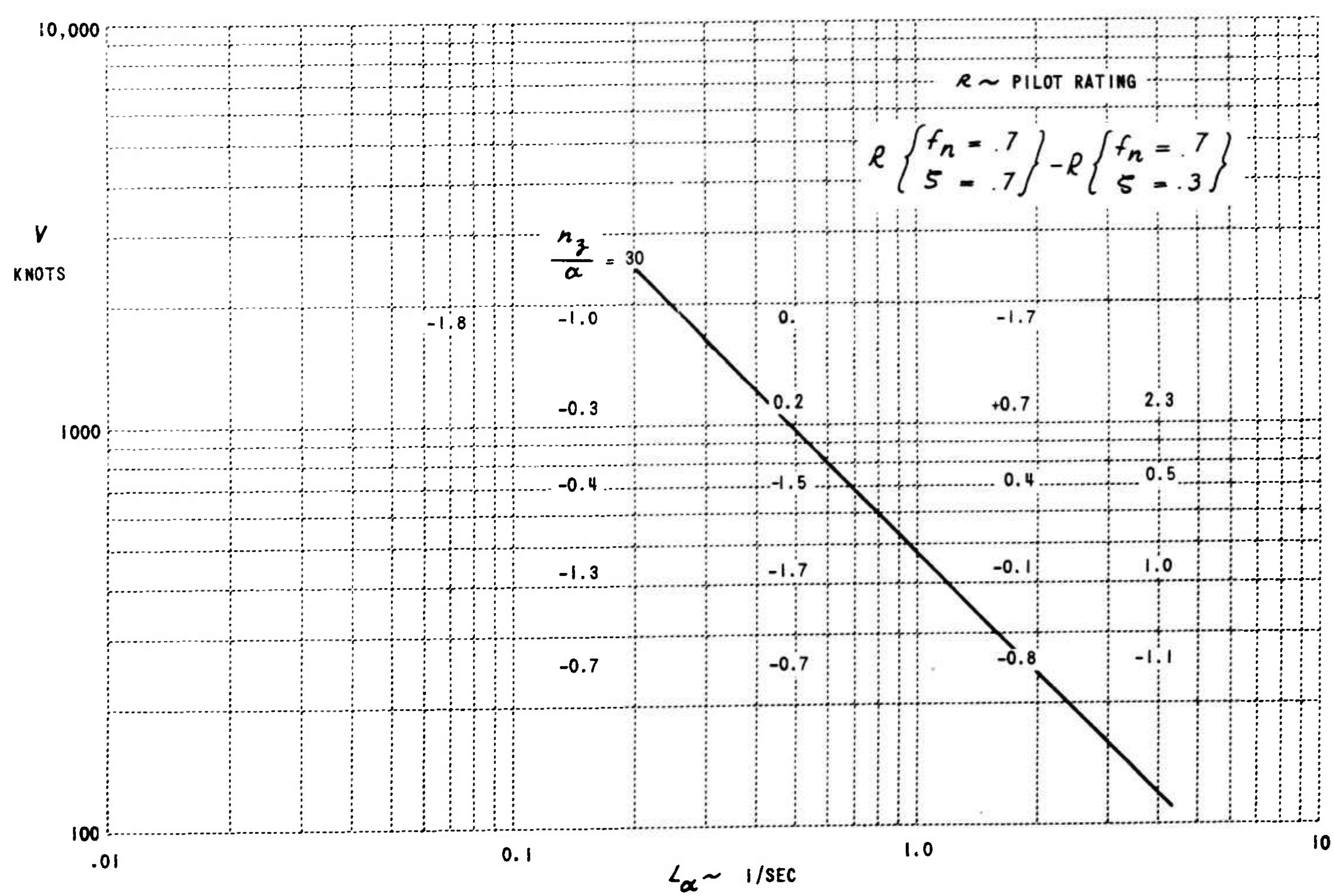


FIGURE 18 COMPARISON OF PILOT RATINGS FOR CONSTANT SHORT PERIOD FREQUENCY

The rough air caused essentially no degradation in the pilot rating data when $L_\alpha < 0.5$. This result suggests the possibility of providing gust alleviation through servo actuation of flaps or spoilers to reduce L_α.

In the simulator program the normal acceleration at the c. g., assuming a rigid airframe, was displayed to the pilots. In some cases the pitching motions were noticeably large and the pilots would qualify their ratings by noting that if they were seated far from the c. g. their rating might be influenced by angular accelerations. It should be noted that when an airplane encounters an up-gust for example, it heaves and weather vanes into the gust. The resulting motion for a rigid airframe is such as to diminish the normal acceleration of points ahead of the c. g. and to increase it for points aft of the c. g. If the airframe is elastic then the predominant structural modes must be considered to determine the normal acceleration response at a given location along the fuselage.

4.3 DETAIL PILOT COMMENT DATA

The detailed pilot comment data for all three pilots and all configurations are quite voluminous, but in this section an attempt will be made to extract and summarize those comments which are considered to be most significant. Comment data will be summarized for the same configurations for which time histories were presented in Figure 14a, b and c. The format used in presenting this information is as follows: first, a brief description of the factors which entered into the selection of the longitudinal control sensitivity is given, second, specific comments related to the magnitude of the angle of attack required to maneuver are made, third, the response to rough air is indicated. With the exception of the rough air comments, the summaries in general apply to all three short period poles.

In addition to the comment summaries included in this section, a representative sampling of the verbatim pilot comments is included in Appendix E. This appendix contains the comments of pilots A and B for a selected number of configurations, together with the comments of pilot C for all of the configurations listed in the table on page 19. The verbatim comments have been included in Appendix E because it is believed that they contain sufficient information, in addition to that extracted for the summaries presented in this section, to make their inclusion valuable. Through study of the comment data included in Appendix E the reader can form an appreciation of the complexity of the flight control task from the pilot's point of view and gain some insight into the relative weighing of the various factors which influence the numerical rating assigned by the pilot.

The verbatim comment data have also been included as an example in support of the hypothesis that exploratory handling quality investigations should be designed to use pilot comments as one of the main sources of information. The fact that such investigations are termed handling or flying quality investigations implies that the degree of acceptability of the vehicle to the pilot is of primary concern. There-

fore, it seems logical to ask the pilot whether or not the vehicle is acceptable and if not, what factors are contributing to the unacceptability. Such comments have been found invaluable in developing an understanding of the relative importance of various vehicle characteristics to the general handling quality suitability of the vehicle. Through pilot comments, in many cases the causes of control difficulty can be determined and the reasons for unsatisfactory ratings can be established directly rather than by implications from correlations.

The comment summaries for the configurations considered in Figure 14 a, b and c follow.

Configuration A (V = 1800 kt, L_α = .07, n_z/α = 6.6)

The longitudinal control sensitivity was a compromise between the initial pitch attitude response and steady stick force in turns. Requirement for light stick force in turns results in high attitude gain. The pilot then tends to have difficulty in maintaining precise attitude control.

Large angle of attack required to maneuver:

a. Large drag changes occur, thus throttle coordination is required if airspeed is to be maintained.

b. For abrupt elevator inputs, the pitch rate associated with the rotation about the c. g. is large compared to the steady pitch rate resulting from flight path curvature. The steady pitch rate for a given acceleration is very low because of the high velocity.

c. Large changes in angle of attack produce moderate to small normal accelerations;

1. The bank angle must be restricted to 45° or less because of the large angle of attack required. At this high speed, 1800 knots, the rate of turn is very low for 45° bank.

2. Large attitude changes are required when rolling into and out of turns, must hunt for proper attitude change.

3. In attempting steep turns, large sink rates can develop which require lots of power and a long time to reverse.

Rough Air

Essentially no acceleration response.

Configuration B (V = 1800 kt, $L_\alpha = .5$, $n_z/\alpha = 47.2$)

The longitudinal control sensitivity was a compromise between the steady forces in turns and ability to control normal acceleration. Requirement for light stick force in turns results in high acceleration gain. The pilot feels he can better resolve acceleration changes with lower gain or heavier forces.

Small angle of attack required to maneuver:

a. Drag changes are small, thus throttle coordination is required only for large amplitude maneuvers.

b. For abrupt elevator inputs, the initial attitude change associated with rotation about the c. g. is small but noticeable; it is desirable since it gives indication of acceleration response. The steady pitch rate for a given acceleration is very low because of the high velocity.

c. Small changes in angle of attack result in large normal accelerations:
   1. All bank angles are usable.
   2. Load factor can be exceeded so caution must be used in maneuvering.

The ability to control altitude and rate of climb is poor. Very small pitch attitude changes result in large rates of climb because of the high velocity. An expanded pitch attitude scale is needed.

Rough Air

Accelerations are small, i.e., less than .3g. Disturbances tended to emphasize poor characteristics of $\omega_n = .3$, $\zeta = .3$ configuration which were evident in smooth air.

Configuration C (V = 1800 kt, $L_\alpha = 1.8$, $n_z/\alpha = 170$)

The longitudinal control sensitivity was a compromise between the steady forces in turns and ability to control normal acceleration and rate of climb. Low gain is required to provide g-limiting by control feel and to improve ability to resolve normal acceleration and rate of climb changes.

Very small angle of attack required to maneuver:

a. Elevator control only required, can fly and maneuver with throttle fixed.

b. For abrupt elevator input, the initial attitude change associated with rotation about the c. g. is very small; also the steady pitch rate for a given normal acceleration is very small because of the high velocity. The result is that

the airplane can be maneuvered throughout its normal acceleration envelope with very small pitch attitude changes.

c. Very small changes in angle of attack result in very large normal accelerations:
1. All bank angles are usable.
2. Load factor can be exceeded with very small attitude changes, must choose control gain to provide g-limiting by control feel. Pilot must exercise caution in maneuvering to avoid exceeding load factor.

The ability to control altitude and rate of climb is very poor. Extremely small attitude changes result in large rate of climb changes because of the high velocity.

Airframe structural limits, pilot comfort, and piloting tasks such as altitude holding all combine to establish certain constraints on normal acceleration and rate of climb. In the experiment, when V and n_z/α were both very high the airplane could be maneuvered within these constraints with extremely small changes in pitch attitude. The pitch attitude indicator then became a very insensitive indicator of normal acceleration or rate of climb and the pilots requested that the scale on this instrument be expanded. In the absense of a usable attitude display they extracted information from the rate of climb and normal acceleration instruments.

Rough Air

Short Period Pole $f_n = .7$, $\zeta = .7$

The rough air had an adverse effect on this configuration. Average accelerations of $\pm$ .4 g with peaks of $\pm$ .8 g and fairly high rates of change would be very uncomfortable. Also handling qualities have been degraded. It is difficult to pin down level flight.

Short Period Pole $f_n = .7$, $\zeta = .3$

The rough air had an adverse effect on this configuration. Average accelerations of $\pm$ .5 g with peak over $\pm$ 1 g and a high rate of change would result in very bad ride. This airplane is somewhat dangerous because of the rather poor handling qualities and the high acceleration response.

Short Period Pole $f_n = .3$, $\zeta = .3$

The rough air had a very pronounced effect on this configuration. The acceleration excursions were $\pm$ 2 to 3 g with very rapid reversals. The pilot's ability to hold attitude, altitude, and airspeed was not good. Sooner or later the large acceleration response and poor handling qualities would result in the pilot exceeding the load factor. It is not completely unflyable but it is dangerous.

<u>Configuration D</u> (V = 700 kt, L_{α} = .5, n_z/α = 18.3)

The longitudinal control sensitivity selected was a compromise between light steady forces in turns and a tendency to overcontrol when trying to change normal acceleration or rate of climb. Possibly influenced by friction and breakout force of side controller. That is, a lower gain was selected so pilot could better resolve inputs in presence of friction. Fairly wide range of control gain considered acceptable.

Moderate angle of attack required to maneuver:

a. Throttle coordination with elevator control is considered normal and acceptable. Airspeed control not particularly troublesome.

b. For abrupt elevator inputs, the pitch rate associated with rotation about the c. g. is noticeably larger than the steady pitch rate resulting from flight path curvature. Tends to cause bobble in pitch for small inputs. Initial attitude change tends to give indication of the normal acceleration.

c. Moderate angle of attack produces adequate normal acceleration.
   1. All bank angles are usable.
   2. Attitude change required to hold level turn is noticeable but not objectionable.
   3. Can pull and maintain normal acceleration with precision for f_n = .7, ζ = .7. Some difficulty with other short period configurations.

Some difficulty in establishing desired rate of climb in the case of the f_n = .3, ζ = .3 short period.

Rough air

Accelerations induced are small, i.e., less than $\pm$ .2 g.

Control response in rough air is good.

<u>Configuration E</u> (V = 250 kt, L_{α} = .15, n_z/α = 1.97)

The longitudinal control sensitivity selected was a compromise between the initial pitch attitude response and the steady stick force in turns. Because of difficulty in pinning down the pitch attitude and the abrupt initial response in pitch attitude the pilots selected a low gain; this resulted in heavy forces in turns.

Very large angle of attack required to maneuver.

a. Large drag changes occur, thus the throttle must be coordinated with elevator inputs to maintain airspeed.

b. For abrupt elevator inputs, the pitch rate associated with rotation about the c.g. is large compared to the steady state pitch rate resulting from flight path curvature.

c. Very large changes in angle of attack produce small normal accelerations.
1. The bank angle must be restricted to 30^{o} or less.
2. Very large attitude changes are required when rolling into or out of turns, must hunt for proper attitude change.
3. In attempting turns large sink rates can develop; to recover, the wings must be leveled and power applied. Even then considerable altitude is lost before the rate of sink can be checked. Pilot loses the normal correspondence between flight path and pitch attitude.

Rough Air

Essentially no acceleration response.

Configuration F (V = 250 kt, L_{α} = .5, n_z/α = 6.55)

The longitudinal control sensitivity selected was a compromise between the initial pitch attitude response and the steady stick force in turns. Low gain reduces difficulty in controlling pitch attitude, but the stick forces in turns become too heavy.

Large angle of attack required to maneuver:

a. Large drag changes occur, thus throttle coordination is required if airspeed is to be maintained.

b. For abrupt elevator input, the pitch rate associated with the rotation about the c.g. is large compared to the steady pitch rate resulting from flight path curvature.

c. Large change in angle of attack produces moderate to small normal acceleration.
1. The bank angle must be restricted to 45^{o} or less. At this speed, 250 knots, the rate of turn for 45^{o} bank is satisfactory.
2. Large attitude changes are required when rolling into and out of turns, must hunt for proper attitude change.
3. In attempting steep turns, large sink rates can develop which require lots of power and a long time to recover.

Rough Air

Normal acceleration response was quite small, i.e., less than $\pm$ .1 g. Pitch disturbances were considerable and somewhat objectionable.

<u>Configuration G</u> (V = 250 kt, L_{α} = 4, n_z/α = 52.4)

The longitudinal control sensitivity was a compromise between the steady forces in turns and the tendency to oscillate in pitch. For light stick force there was a tendency for oscillations in pitch which resulted in normal acceleration and rate of climb changes.

Small angle of attack required to maneuver:

a. Drag changes are small, thus throttle coordination is required only for large amplitude maneuvers.

b. For abrupt elevator inputs, the pitch rate associated with the rotation about the c.g. is of the same order of magnitude as the pitch rate resulting from flight path curvature.

c. Small changes in angle of attack result in large normal accelerations.
   1. All bank angles are usable.
   2. Load factor can be exceeded so caution must be used in maneuvering.
   3. Some difficulty in establishing and maintaining precise rate of climb.

Rough Air

<u>Short Period Pole: f_n = .7, ζ = .7</u>

An uncomfortable configuration that would require considerable attention from the pilot. Normal accelerations average $\pm$ .4 g.

<u>Short Period Pole f_n = .7, ζ = .3</u>

This configuration was quite bad in rough air. Normal accelerations of $\pm$ 1 g were frequently experienced. Pilot fatigue would develop rapidly.

<u>Short Period Pole f_n = .3, ζ = .3</u>

This configuration was unflyable because the normal acceleration resulting from the rough air exceeded the 3.5 g structural limits of the airframe.

SECTION 5

CONCLUSIONS

A fixed-base simulator experiment has been conducted to investigate the effects of true speed and the parameter $L_\alpha = \frac{\rho S V}{2m} C_{L_\alpha}$ on the longitudinal flying qualities of piloted aircraft. The major conclusions are:

1. The longitudinal control gain selected by the pilots was a compromise which weighed the often conflicting requirements for good pitch attitude control, adequate g-limiting protection and satisfactory steady forces in turns.
   a. For n_z/α less than approximately 10 g/rad, the pilots tended to choose constant pitch attitude gain in the frequency band $1 < \omega < 3$ rad/sec.
   b. For n_z/α greater than approximately 10 g/rad the pilots tended to choose constant normal acceleration gain in the frequency band $1 < \omega < 3$ rad/sec.
   c. The average longitudinal control gain that was considered optimum by one pilot differed by a factor of two from that considered optimum by another pilot.
   d. The ratio of static-to-short period-gain in the pitch attitude transfer function was not found to be of significance to the pilots in their selection of the optimum longitudinal gain or in their evaluation rating.

2. In smooth air, pilot acceptance of longitudinal flying qualities is a function of the parameter $n_z/\alpha \cong L_\alpha V/g$
   a. The most satisfactory ratings were obtained when $5 < n_z/\alpha < 80$ g/rad.
   b. Unacceptable ratings tended to result when $n_z/\alpha < 5$ g/rad or $n_z/\alpha > 80$ g/rad. The unacceptable ratings at low n_z/α were based primarily on the difficulty in maintaining airspeed and the restriction on usable bank angle.
      The unacceptable ratings at high n_z/α were based primarily on the difficulty in controlling normal acceleration and rate of climb and on the inadequacy of the pitch attitude indicator as a source of information.

c. The results of previous investigations of the effect of short period dynamics on longitudinal flying qualities must be qualified since these investigations were in general conducted at specific values of L_α and V or n_z/α. If n_z/α falls in the optimum range, the regions of optimum and acceptable characteristics in terms of short period frequency and damping ratio are broader than otherwise. Conversely, for less desirable values of n_z/α the more demanding the requirements for good values of short period frequency and damping ratio.

d. When n_z/α and V were both large, the pilots found the pitch attitude indicator used in the experiment (Lear Remote Attitude-Direction Indicator, Type ARU-2/A) inadequate for the flight control task. That is, nearly undetectable changes in the attitude display corresponded to quite large normal acceleration and rate of climb responses. This result indicates the need for improved sensor and display equipment for high speed, high dynamic pressure flight.

3. The primary factors which determine the normal acceleration response of a rigid airplane to rough air are L_α, f_n, ζ and V together with the frequency spectrum characteristics of the rough air.

a. If L_α is low the normal acceleration response is small for nearly all values of the other factors; however, if L_α is high the acceleration response is lessened by a high short period frequency and a high short period damping ratio.

b. The effect of velocity change is to change the frequency spectrum of the turbulence encountered.

SECTION 6

REFERENCES

1. Infanti, Nello L.: Augmented Capabilities of the Variable Stability T-33 Airplane for Ground and Flight Handling Qualities Evaluations. CAL Report No. TE-1243-F-1, November 1960.

2. Walker, W. G., and Copp, M. R.: Summary of VGH and V-G Data Obtained from Piston-Engine Transport Airplanes from 1947 to 1958. Langley Research Center, NASA TN D-29, September 1959.

3. Truxal, John G.: Automatic Feedback Control System Synthesis. McGraw-Hill Book Company, New York, 1955.

4. Chalk, C. R.: Additional Flight Evaluations of Various Longitudinal Handling Qualities in a Variable Stability Jet Fighter. WADC TR 57-719, Part 2 (CAL Report No. TB-1141-F-2).

5. Kidd, E. A. and Bull, G.: Handling Qualities Requirements as Influenced by Pilot Evaluation Time and Sample Size. CAL Report No. TB-1444-F-1, February 1963.

6. Bull, G.: Minimum Flyable Longitudinal Handling Qualities of Airplanes. CAL Report No. TB-1313-F-1, December 1959.

7. Bull, G. and Kidd, E. A.: Air-to-Air Tracking with Linear and Non-Linear Yaw Damping. WADC TR 55-223 (CAL Report No. TB-697-F-2), June 1955.

8. Kidd, E. A. and Harper, R. P., Jr.: Fixed-Base and In-Flight Simulations of Longitudinal and Lateral-Directional Handling Qualities for Piloted Re-Entry Vehicles. ASD-TDR-61-362 (CAL Report TB-1516-F-1), March 1963.

9. Dynamics of the Airframe. BuAer Report AE-61-411, September 1952.

10. McRuer, D., Ashkenas, I., Guerre, C.: A Systems Analysis View of Longitudinal Flying Qualities. WADD TR 60-43, January 1960.

11. Sadoff, M., McFadden, N., Heinle, D.: A Study of Longitudinal Control Problems at Low and Negative Damping and Stability with Emphasis on Effects of Motion Cues. NASA TN D-348, January 1961.

12. Jex, H., Cromwell, C., III: Theoretical and Experimental Investigation of Some New Longitudinal Handling Qualities Parameters. ASD-TR-61-26, June 1962.

13. Harper, R. P., Jr.: Flight Evaluations of Various Longitudinal Handling Qualities in a Variable-Stability Jet Fighter. WADC TR 55-299. (CAL Report No. TB-757-F-12) July 1955

APPENDIX A

DETAILS OF SIMULATION EQUIPMENT

A.1 EQUATIONS MECHANIZED

The airplane was simulated on the analog computer by the following limited six-degree-of-freedom equations: (Force equations are referenced to stability axes, moment equations are referenced to body axes.)

$$\Delta\dot{V}m = X_s - P_{s_x} - mg(\Theta - \alpha\cos\phi) \tag{A-1}$$

$$V(\dot{\alpha} - q)m = Z_s + mg\cos\phi \tag{A-2}$$

$$V(\dot{\beta} + r - \alpha p)m = Y_s + mg\sin\phi \tag{A-3}$$

$$\dot{q}I_{YY} = M \tag{A-4}$$

$$\dot{p}I_{XX} - \dot{r}I_{XZ} = L \tag{A-5}$$

$$\dot{r}I_{ZZ} - \dot{p}I_{XZ} = N \tag{A-6}$$

$$\dot{\phi} = p + \dot{\psi}\Theta \tag{A-7}$$

$$\dot{\Theta} = q\cos\phi - r\sin\phi \tag{A-8}$$

$$\dot{\psi} = r\cos\phi + q\sin\phi \tag{A-9}$$

$$\dot{h} = (V + \Delta V)(\Theta - \alpha\cos\phi - \beta\sin\phi) \tag{A-10}$$

The above equations incorporate the following assumptions:

1. α, β, Θ_w, Θ are small angles
2. $\cos\alpha \cong \cos\beta \cong 1$

   $\sin\alpha \cong \alpha$, $\sin\beta \cong \beta$
3. $\cos\Theta_w \cong 1$

   $\sin\Theta_w \cong \Theta_w \cong (\Theta - \alpha\cos\phi)$ in X-force equation

   $\cong (\Theta - \alpha\cos\phi - \beta\sin\phi)$ in rate of climb equation
4. $\cos\Theta \cong 1$

   $\sin\Theta \cong \Theta$
5. Products, squares of p, q, r = 0

The aerodynamic terms in the above equations were approximated by the following expansions:

$$-X_s = q_o S\left[C_{D_o} + C_{D_\alpha}\alpha + C_{D_{\alpha^2}}\alpha^2\right] + q_o S\frac{2}{V}\left[C_{D_o}\Delta V + C_{D_\alpha}\alpha\Delta V + C_{D_{\alpha^2}}\alpha^2\Delta V\right] \quad \text{(A-11)}$$

$$Y_s = q_o S\left[C_{Y_\beta}\beta + C_{Y_{\delta_r}}\delta_r\right] \quad \text{(A-12)}$$

$$-Z_s = q_o S\left[C_{L_o} + C_{L_\alpha}\alpha + C_{L_{\delta_e}}\delta_e\right] + q_o S\frac{2}{V}\left[C_{L_o}\Delta V + C_{L_\alpha}\alpha\Delta V\right] \quad \text{(A-13)}$$

$$L = q_o Sb\left[C_{\ell_\beta}\beta + C_{\ell_{\delta_a}}\delta_a + C_{\ell_{\delta_r}}\delta_r\right] + q_o Sb\left(\frac{b}{2V}\right)\left[C_{\ell_p}p + C_{\ell_r}r\right] \quad \text{(A-14)}$$

$$M = q_o Sc\left[C_{m_\alpha}\alpha + C_{m_{\delta_e}}\delta_e\right] + q_o Sc\left(\frac{c}{2V}\right)\left[C_{m_{\dot\alpha}}\dot\alpha + C_{m_q}q\right] \quad \text{(A-15)}$$

$$N = q_o Sb\left[C_{n_\beta}\beta + C_{n_{\delta_a}}\delta_a + C_{n_{\delta_r}}\delta_r\right] + q_o Sb\left(\frac{b}{2V}\right)\left[C_{n_p}p + C_{n_r}r\right] \quad \text{(A-16)}$$

Reference 1 contains a brief discussion of the derivation of the expansion of the lift and drag aerodynamic terms. This reference also contains analog schematic diagrams which indicate the basic method employed to mechanize the analog; however, for this study the problem was rescaled and remechanized in some respects.

For the simulation program reported here, X_s and Y_s aerodynamic force equations and the L and N aerodynamic moment equations were identical for all configurations. The numerical values used were those of the T-33 airplane at h_p = 25, 000 feet and an indicated airspeed of IAS = 250 knots. Angles and rates are in degrees and degrees per second.

$$-X_s = 948 + 72.2\alpha + 50\alpha^2 + 3.1\Delta V + .238\alpha\Delta V + .162\alpha^2\Delta V \quad \text{(A-17)}$$

$$Y_s = -666\beta + 154.5\delta_r \quad \text{(A-18)}$$

$$L = -2050\beta - 3840\delta_a + 615\delta_r - 603p + 80.9r \quad \text{(A-19)}$$

$$N = 2200\beta + 32.6\delta_a - 1670\delta_r - 2.16p - 186r \quad \text{(A-20)}$$

The Z_s aerodynamic force equation and M aerodynamic moment equation were modified for each configuration as follows:

$$-Z_s = mg + \frac{mV}{57.3}L_\alpha\alpha + \frac{mV}{57.3}L_\delta\delta_e + \frac{2mg}{V}\Delta V + \frac{2m}{57.3}L_\alpha\alpha\Delta V \quad \text{(A-21)}$$

$$M = \frac{I_{YY}}{57.3}M_\alpha\alpha + \frac{I_{YY}}{57.3}M_{\dot\alpha}\dot\alpha + \frac{I_{YY}}{57.3}M_q q - 4790\delta_e \quad \text{(A-22)}$$

where

L_α and V ~ independent variables

$M_\alpha, M_{\dot{\alpha}}, M_q$ ~ selected to define short period

L_δ ~ selected to maintain numerator breakpoint of n_z/δ_e transfer function constant (see Appendix C)

$$\frac{1}{\tau_1 \tau_2} = -M_\alpha + \frac{L_\alpha}{L_\delta} M_\delta = -371 \qquad \text{(A-23)}$$

W = 12,840 lb $\qquad I_{xx}$ = 13,500 slug-ft^2

I_{xz} = 485 slug-ft^2 $\qquad I_{yy}$ = 20,700 slug-ft^2

I_{zz} = 33,000 slug-ft^2

Note that the lift at zero angle of attack was made equal to the weight, thus the configurations were all trimmed at zero angle of attack regardless of the value of L_α or true speed being simulated.

The engine thrust for full throttle, P_{s_x} was 13,500 lb. This permitted balancing the drag equation for angles of attack up to $\alpha = 15^\circ$.

A.2 SIMULATION OF ATMOSPHERIC TURBULENCE

Experience has indicated that it is advisable to have the airplane disturbed by an external input when doing pilot evaluations of vehicle handling qualities. For the evaluation program considered herein, it was decided to use a simplified simulation of atmospheric turbulence as the external disturbance. The following assumptions were used in the simulation:

1. The airplane flies through turbulent air which has rms vertical velocity of $\sqrt{\overline{w_{a.g.}^2}}$ = 6.5 ft/sec. The probability of encountering turbulence equal to or greater than this magnitude at low altitude is 5% (Reference 2).
2. The gust induced angle of attack is $\alpha_{a.g.} = \dfrac{w_{a.g.}}{V}$
3. The gust induced angle of attack enters the lift equation proportional to L_α and the moment equation proportional to M_α.
4. There are no roll, lateral, or directional inputs.
5. Maximum wave length is 1000 feet.

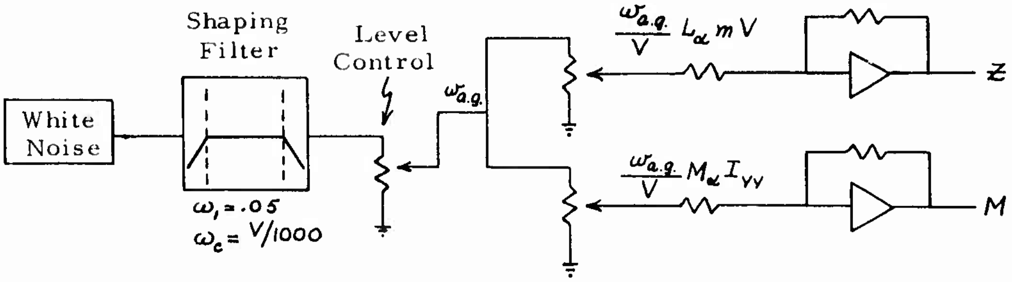
6. The vertical gust velocity is obtained by passing white noise through a shaping filter.

7. The shaping filter is a band pass filter with the low frequency corner at $\omega_1 = .05$ rad/sec and the high frequency corner at $\omega_c = V/1000$ rad/sec where V is in ft/sec.

The transfer function of the filter used to shape the white noise was as follows:

$$G(s) = \frac{K\omega_c\, s}{(s+.05)(s+\omega_c)} \qquad \text{(A-24)}$$

Schematically:



The mean square gust velocity can be expressed by the following equation (Reference 3):

$$\overline{w_{ag}^{\,2}} = \frac{1}{2\pi}\int_{-\infty}^{\infty} \left|KG(j\omega)\right|^2 \Phi_{nn}(j\omega)\, d\omega \qquad \text{(A-25)}$$

For white noise the power spectral density is constant for all frequencies.

$$\Phi_{nn}(j\omega) = C_n \qquad \text{(A-26)}$$

Thus

$$\overline{w_{ag}^{\,2}} = \frac{C_n}{2\pi}\int_{-\infty}^{\infty} \left|\frac{K(V/1000)\, j\omega}{(j\omega+.05)(j\omega+V/1000)}\right|^2 d\omega \qquad \text{(A-27)}$$

This integral can be evaluated by evaluating the summation of residues in left-half plane (Reference 3) with the result:

$$\overline{w_{ag}^{\,2}} \cong \frac{C_n K^2}{2}\left[\frac{V}{1000} - .05\right] \qquad \text{(A-28)}$$

The rms voltage at the output of the filter is

$$\sqrt{\overline{w_{ag}^2}} = K \sqrt{\frac{C_n}{K}} \sqrt{\frac{V}{1000} - .05} \qquad \text{(A-29)}$$

Since the constant C_n was not readily available, the level control was adjusted by trial for a reference velocity of V = 613 ft/sec until $\sqrt{\overline{w_{a.g.}^2}} = 6.5$ ft/sec was obtained. For other airplane nominal speeds, the filter corner was adjusted by the relation, $\omega_c = V/1000$, and the level control was adjusted to maintain the rms vertical gust velocity at $\sqrt{\overline{w_{a.g.}^2}} = 6.5$ ft/sec by the following relation.

$$K_V = K_{613} \sqrt{\frac{\frac{613}{1000} - .05}{\frac{V}{1000} - .05}} \qquad \text{(A-30)}$$

$$= K_{613} \sqrt{\frac{563}{V-50}} \qquad \text{(A-31)}$$

A graphical illustration of the contribution to $\overline{w_{a.g.}^2}$ from different frequency bands can be obtained through the following manipulation and plotting technique.

The simulated mean square turbulence is expressed by equation A-27. If this expression is multiplied and divided by ω

$$\overline{w_{ag}^2} = \frac{C_n}{2\pi} \int_{-\infty}^{\infty} \omega \left| KG(j\omega) \right|^2 \frac{d\omega}{\omega} \qquad \text{(A-32)}$$

and it is noted that $\frac{d\omega}{\omega} = d(\ln \omega)$ then (A-32) can be written

$$\overline{w_{ag}^2} = \frac{C_n}{2\pi} \int_{-\infty}^{\infty} \omega \left| KG(j\omega) \right|^2 d(\ln \omega) \qquad \text{(A-33)}$$

If $\omega \left| KG(j\omega) \right|^2$ is plotted vs. ω using a logarithmic scale for the frequency, the shape of the resulting curve illustrates at a glance the frequencies which contribute most to $\overline{w_{a.g.}^2}$ since the area under the curve is equal to

$\frac{2\pi}{C_n} \overline{w_{a.g.}^2}$.

Figure A-4 illustrates the simulated turbulence spectra used in the ground simulator program for each of the nominal test velocities. Although the mean square gust velocity was constant, the distribution with frequency was different at each velocity and this fact is graphically illustrated by the curves of Figure A-4.

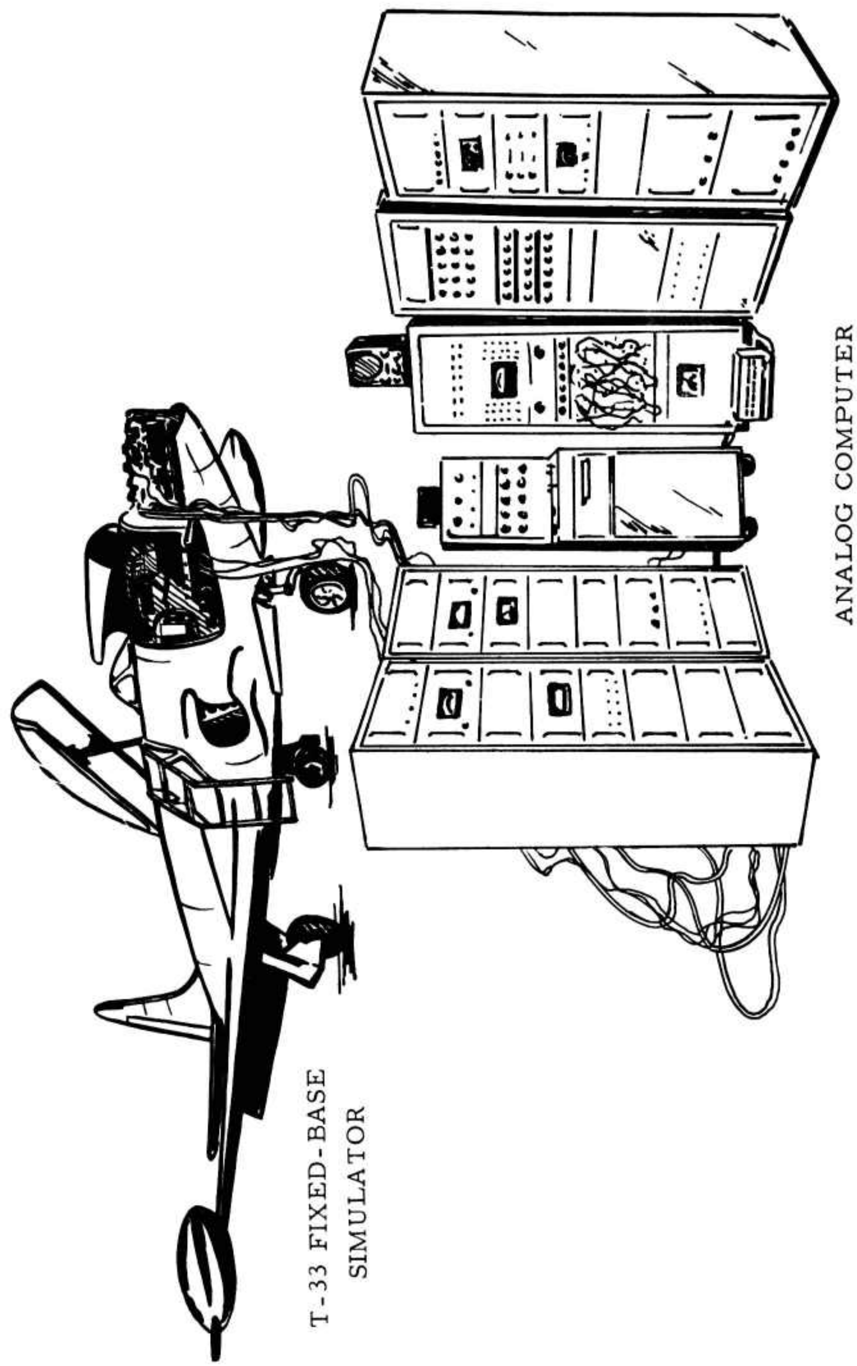


FIGURE A-1 GENERAL ARRANGEMENT OF SIMULATOR

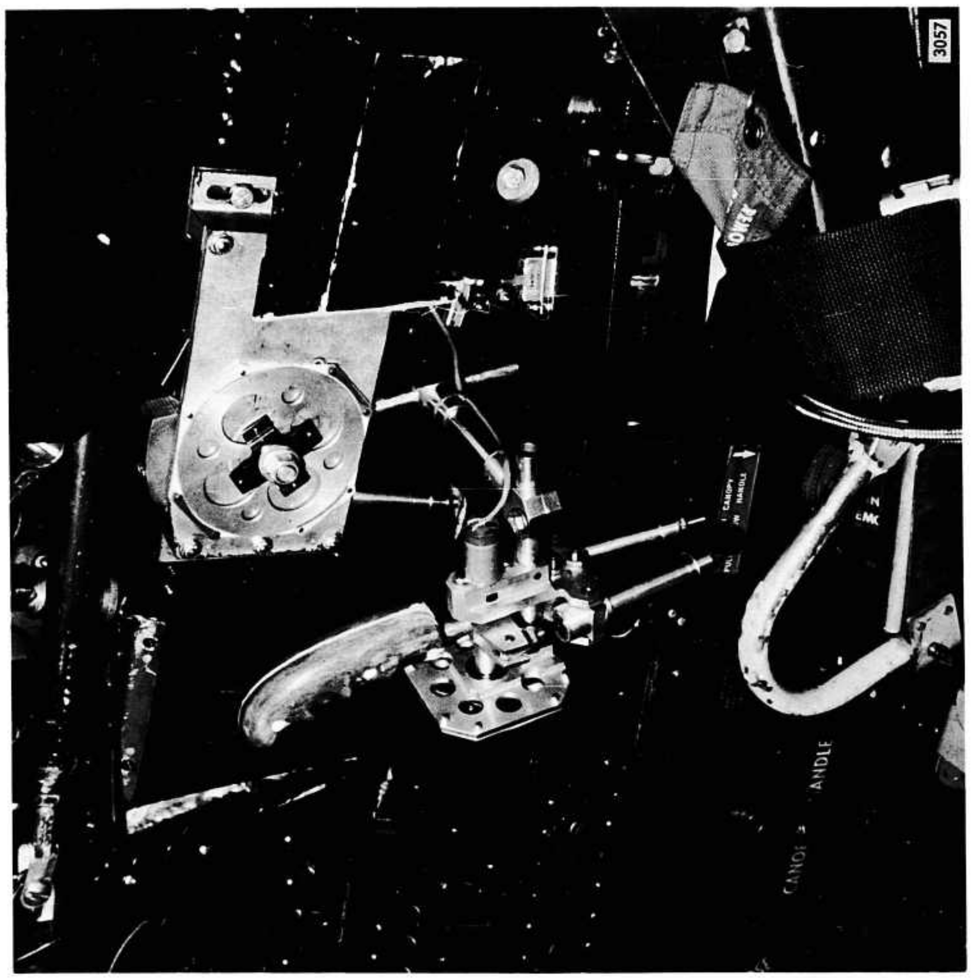


FIGURE A-2 SIDE STICK CONTROLLER IN T-33

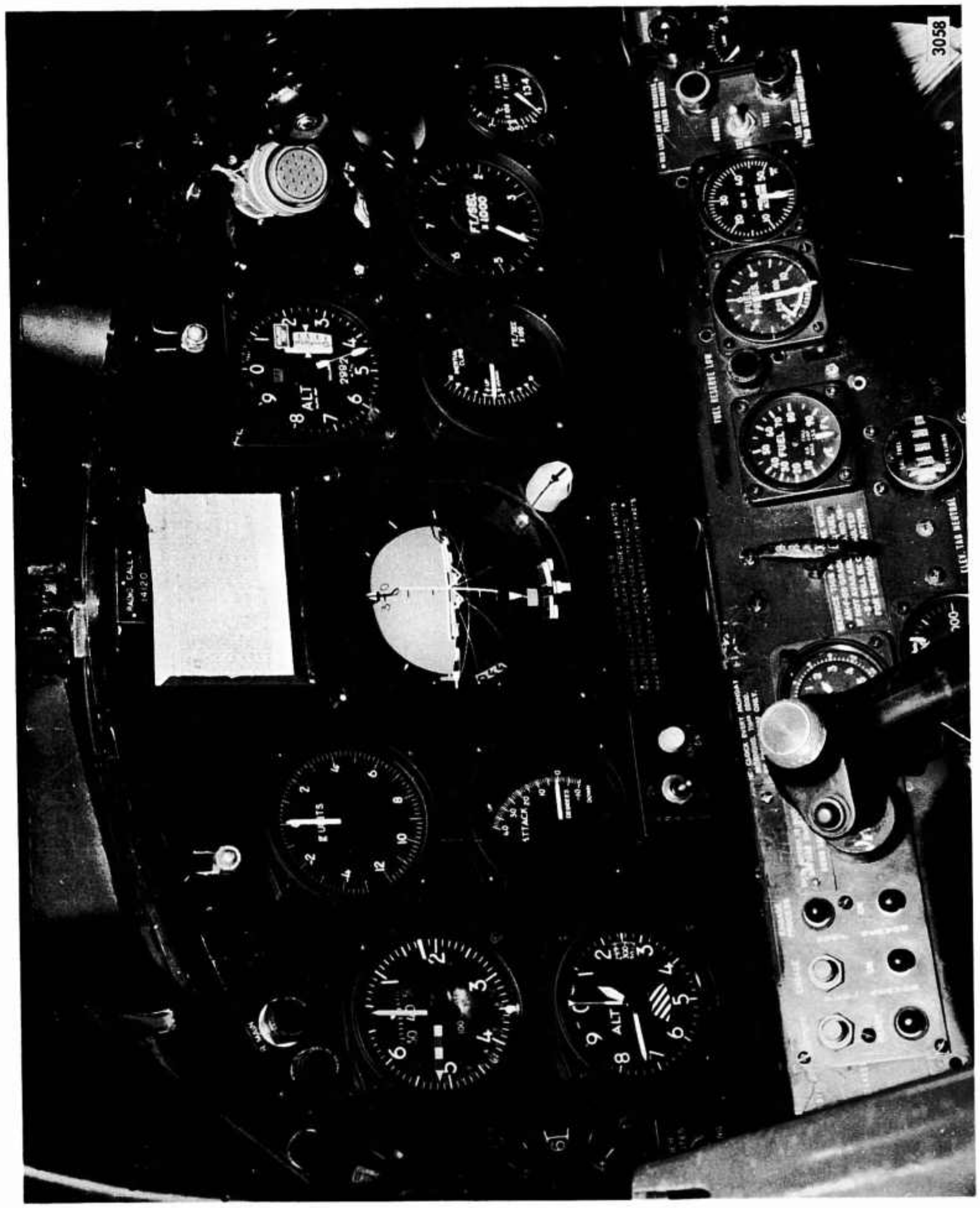


FIGURE A-3 COCKPIT INSTRUMENT PANEL

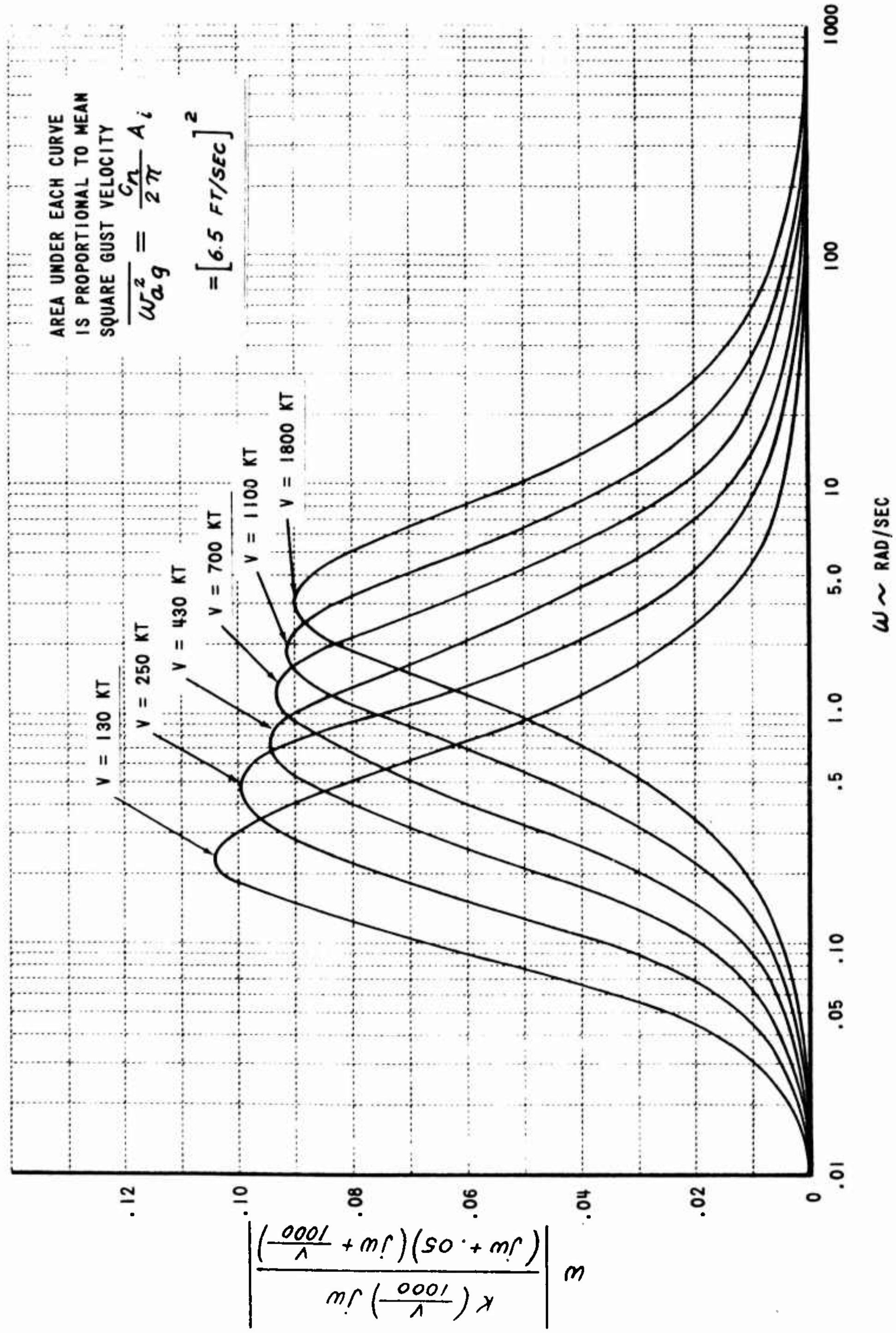


FIGURE A-4 SIMULATED TURBULENCE SPECTRA

APPENDIX B

INSTRUCTIONS TO PILOTS

B.1 INTRODUCTION

The program is designed to obtain information on the effects of true speed and L_α on longitudinal handling qualities.

Past programs for longitudinal handling qualities have been directed at short period and phugoid dynamic characteristics. The airplanes in which these tests were done were flown at specific flight conditions such that the parameters L_α, and the true speed, V, were constant for all configurations in each test series. Not only were these parameters held constant, they were held constant at reasonably well matched values such that if attitude control were satisfactory, then flight path control was also satisfactory. In the planned simulator program, L_α and V will be varied independently through large ranges for several short period configurations. The primary effects of these parameters should appear in the ability of the pilot to control the vehicle flight path through space. For some configurations, large attitude changes will result in very little "g" response and very slow response in flight path changes; while for other configurations, almost undetectable changes in attitude will result in large and immediate changes in "g" and rate of climb.

The effects of true speed are independent of the aircraft and are a result of kinematics. For example, pitch rate associated with a steady pull-up is as follows:

$$\dot{\theta} = \frac{g}{V}\left(n_z - \cos\gamma\right)$$

Thus for a given steady state normal acceleration, smaller pitch rates will be required as the true speed is increased. The steady rate of turn at constant altitude is related to velocity and bank angle as follows:

$$\dot{\psi} = \frac{g}{V}\tan\phi$$

Thus for a given rate of turn, larger bank angles will be required as true speed is increased. The rate of climb is related to speed and the flight path angle, γ, by the following expression:

$$\dot{h} = V\sin\gamma$$

Thus a given flight path angle will result in larger and larger rates of climb or descent as the true speed is increased.

The above described effect of true speed on the relation between responses is strictly the result of kinematics and is completely independent of the aircraft configuration. For this reason true speed will be displayed

to the pilots. This situation must be appreciated by the evaluation pilot so that he can properly arrive at a rating. For example, a configuration should not be given a low rating because certain pitch rates or yaw rates cannot be attained with a given normal acceleration or bank angle range. If the airplane is required to operate at a certain speed and at this speed it takes half the state of New York to make a turn using 30° bank, then this is a fact of life and should not be the basis for downrating a configuration.

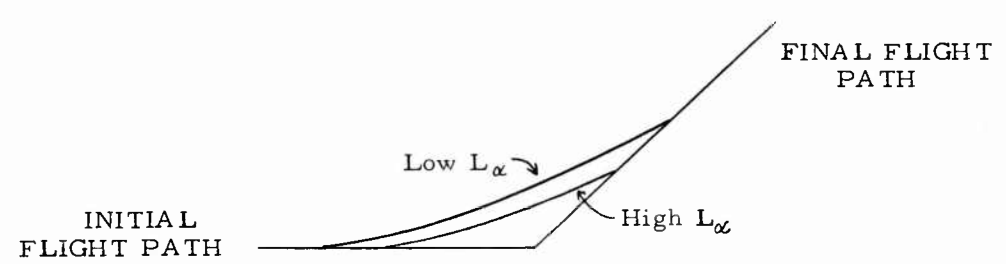
The parameter L_α can be expressed as follows:

$$L_\alpha = \frac{q_0 S}{mV} C_{L_\alpha}$$

From this expression it can be seen that at a given velocity, wide ranges of this parameter can be experienced by various combinations of aircraft mass, wing area, dynamic pressure, and slope of the lift curve. The primary effect of this parameter on handling qualities should appear in the pilot's ability to control the vehicle flight path. The expression for L_α can be thought of as the following ratio:

$$L_\alpha = \frac{\Delta \text{ Lift}/\Delta\alpha}{\text{Linear Momentum}}$$

The ratio is a measure of the effectiveness of changes in angle of attack in bending the aircraft flight path.



Another effect of L_α will be evident when flying through rough air. The magnitude of L_α will be important in determining how rough the ride will be; i. e., configurations with low L_α will experience smaller normal acceleration changes than configurations with high L_α.

B.2 PROCEDURE

It is planned to study the configurations in groups of twelve. All configurations in a group of twelve will be at the same speed, the configurations will vary in the value of L_α and the short period dynamics. A number of configurations will be repeated during the program so that a "set" at a given speed will consist of more than twelve runs.

The pilots will select the value of elevator gear ratio most compatible with each configuration and then proceed with the actual evaluation. The evaluations will be conducted in two parts, first in "smooth air" and second in simulated "rough air". Two separate ratings will be assigned to each configuration.

The smooth air evaluation task will be, in general, to determine how easy or difficult it is to maintain precise control of the vehicle's flight path through space. This will be evaluated on the basis of the pilot's ability to:

1. Hold altitude,
2. Make turns,
3. Make specific changes in altitude, and
4. Maintain speed.

The numerical ratings will be assigned using the rating scale defined herein. The ratings will be based on the amount of work the pilot must put forth to achieve the precision of flight path control that he believes is satisfactory.

Thus, the criteria for satisfactory precision of control of the vehicle's flight path is left to each pilot to establish and apply. If each pilot is consistent in the criteria he uses for arriving at a numerical rating, the resulting data should be useful and informative.

Upon completion of the "smooth air" evaluation and rating, the pilot will examine the configuration in simulated "rough air". This evaluation will be conducted to determine whether the rough air causes any unforeseen difficulties in control and to evaluate the severity of the ride that might be expected for flight in continuous turbulence. It is requested that this evaluation be done using the same gear ratio selected for smooth air and that the time spent in examining the configuration in rough air be limited to the order of five minutes. During this time, a two-minute oscillograph recording will be taken during which the pilot will attempt to minimize deviations in attitude, altitude, and airspeed. As indicated above, the rating assigned at the end of the rough air evaluation will be based on both the ability to maintain satisfactory control of the flight path and the ability of the pilot to perform in the acceleration environment.

In addition to the numerical ratings, pilot comments will be recorded. From the pilot comment data, information will be obtained on how the combinations of short period, V, and L_α affect the handling qualities of airplanes. Comments are solicited on any aspect that the pilot feels is significant. In particular, comments on special piloting techniques required to control the flight path for certain configurations, or changes in instruments used are of interest. Comments on the adequacy of the instruments for the task are also of interest.

The pilots will be provided with "flight cards" containing the following instructions and information.

SMOOTH AIR

EVALUATION MANEUVERS

1. Trim airplane.
2. Straight and level flight, including small pilot-initiated disturbances about level flight.
3. Heading changes maintaining constant altitude. Examine usable bank angles.
4. Specific altitude changes.
5. Climbing and descending turns.

PILOT COMMENT CHECK LIST

1. Is the airplane difficult to trim?
2. Is attitude control satisfactory?
3. Is normal acceleration control a problem?
4. What factors entered into your selection of elevator gear ratio?
5. Can you hold altitude?
   a. Straight and level
   b. Turns
6. What bank angle range is usable?
7. Is maintaining airspeed a problem?
8. Is a special piloting technique required?
9. What instruments are you using most?
10. Are any of the instruments inadequate for this configuration?

ROUGH AIR

EVALUATION MANEUVERS

1. Minimize attitude, altitude, and speed changes while flying through simulated rough air.
2. Smooth air maneuvers at pilot's discretion.

PILOT COMMENT CHECK LIST

1. Has the rough air brought forth any characteristics of the configuration that would affect your ability to control the flight path of this configuration?
2. Could you control this configuration for one-half hour in turbulence of this intensity?

RATING SCALE

Category	Adjective Description Within Category	Numerical Rating
Acceptable	Excellent	1
and	Good	2
Satisfactory	Fair	3
Acceptable	Fair	4
but	Poor	5
Unsatisfactory	Bad	6
	Bad	7
Unacceptable	Very bad	8
	Dangerous	9
	Unflyable	10

Additional Definitions of Unacceptable Category:

7 Bad - Aircraft controllable, but requires major portion of pilot's attention.

8 Very Bad - Aircraft controllable, but only with a minimum of cockpit duties.

9 Dangerous - Aircraft just controllable with complete attention

10 Unflyable

APPENDIX C

LONGITUDINAL TRANSFER FUNCTIONS

C.1 ELEVATOR INPUT

In this appendix, several simplified longitudinal transfer functions are developed in support of the discussion in the text. The following equations of motion are used to represent the airplane for this purpose. They assume constant speed and neglect incremental effects of gravity.

$$\ddot{\Theta} = M_q \dot{\Theta} + M_{\dot{\alpha}} \dot{\alpha} + M_\alpha \alpha + M_\delta \delta_e \tag{C-1}$$

$$\dot{\alpha} = \dot{\Theta} - L_\alpha \alpha - L_\delta \delta_e \tag{C-2}$$

$$\dot{\gamma} = \dot{\Theta} - \dot{\alpha} \tag{C-3}$$

$$n_z = \frac{V}{g} \dot{\gamma} \tag{C-4}$$

The equations imply that the reference axes are stability axes and that the wings are always level so that $\dot{\Theta}$ = q and $\Theta(s) = \frac{1}{s} \dot{\Theta}(s)$. The dependent variables (Θ , α , δ_e and γ) are incremental values from the reference condition.

The following transfer functions arise from Equations C-1 thru C-4.

$$\frac{\dot{\Theta}(s)}{\delta_e(s)} = \frac{(M_\delta - L_\delta M_{\dot{\alpha}})s + (M_\delta L_\alpha - M_\alpha L_\delta)}{s^2 + (L_\alpha - M_q - M_{\dot{\alpha}})s + (-M_\alpha - M_q L_\alpha)} \tag{C-5}$$

$$\frac{\alpha(s)}{\delta_e(s)} = \frac{-L_\delta s + (M_\delta + M_q L_\delta)}{s^2 + (L_\alpha - M_q - M_{\dot{\alpha}})s + (-M_\alpha - M_q L_\alpha)} \tag{C-6}$$

$$\frac{n_z(s)}{\delta_e(s)} = \frac{V}{g} \; \frac{L_\delta s^2 + (-L_\delta M_q - L_\delta M_{\dot{\alpha}})s + (M_\delta L_\alpha - M_\alpha L_\delta)}{s^2 + (L_\alpha - M_q - M_{\dot{\alpha}})s + (-M_\alpha - M_q L_\alpha)} \tag{C-7}$$

The short period natural frequency and damping ratio are expressed as:

$$\omega_n^2 = -M_\alpha - M_q L_\alpha \tag{C-8}$$

$$\zeta = \frac{L_\alpha - M_q - M_{\dot{\alpha}}}{2\omega_n} \tag{C-9}$$

The transfer functions may be written in lumped parameter form as:

$$\frac{\dot{\Theta}(s)}{\delta_e(s)} = \frac{K_{\dot{\Theta}} (\tau_{\dot{\Theta}} s + 1)}{\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n} s + 1} \tag{C-10}$$

(C-11)

$$\frac{\alpha(s)}{\delta_e(s)} = \frac{K_\alpha (\tau_\alpha s + 1)}{\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n} s + 1} \tag{C-11}$$

$$\frac{n_z(s)}{\delta_e(s)} = \frac{K_{n_z} (\tau_1 s + 1)(\tau_2 s + 1)}{\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n} s + 1} \tag{C-12}$$

where:

$$K_\alpha = \frac{M_\delta + M_q L_\delta}{-M_\alpha - M_q L_\alpha} \approx \frac{M_\delta}{\omega_n^2} \tag{C-13}$$

$$K_{\dot\theta} = \frac{M_\delta L_\alpha - M_\alpha L_\delta}{-M_\alpha - M_q L_\alpha} \approx \frac{M_\delta L_\alpha}{\omega_n^2} \tag{C-14}$$

$$K_{n_z} = \frac{V}{g} K_{\dot\theta} \approx \frac{V}{g}\,\frac{M_\delta L_\alpha}{\omega_n^2} \tag{C-15}$$

$$\tau_{\dot\theta} = \frac{M_\delta - M_{\dot\alpha} L_\delta}{M_\delta L_\alpha - M_\alpha L_\delta} \approx \frac{1}{L_\alpha} \tag{C-16}$$

$$\tau_\alpha = \frac{-L_\delta}{M_\delta + M_q L_\delta} \tag{C-17}$$

$$\frac{1}{\tau_1 \tau_2} = -M_\alpha + \frac{L_\alpha}{L_\delta} M_\delta \tag{C-18}$$

$$\tau_1 + \tau_2 = \frac{-L_\delta (M_q + M_{\dot\alpha})}{M_\delta L_\alpha - M_\alpha L_\delta} \tag{C-19}$$

For the study reported here the value of M_δ was held constant for all configurations and L_δ was adjusted for each configuration such that the value of $1/\tau_1\tau_2$ in the normal acceleration transfer function was maintained constant at $1/\tau_1\tau_2 = -371\ 1/\text{sec}^2$. For all configurations studied the numerator quadratic of this transfer function consisted of two real roots of nearly equal magnitude but of opposite sign, $1/\tau_1 \approx -1/\tau_2 \approx 19.25$. Since the highest short period frequency studied was $\omega_n = 4.4$ rad/sec, the normal acceleration transfer function is approximated as follows:

$$\frac{n_z(s)}{\delta_e(s)} = \frac{K_{n_z}}{\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n}s + 1} \tag{C-20}$$

Also, $1/\tau_\alpha$ is very large relative to the short period frequency; therefore, the angle of attack transfer function is approximated as:

$$\frac{\alpha(s)}{\delta_e(s)} = \frac{K_\alpha}{\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n}s + 1} \tag{C-21}$$

The relative amplitude and phase of the various airplane responses to elevator control can be obtained by taking the ratio of the particular transfer functions for elevator input.

$$\frac{n_z(s)}{\dot\theta(s)} = \frac{n_z(s)/\delta_e(s)}{\dot\theta(s)/\delta_e(s)} \tag{C-22}$$

$$= \frac{K_{n_z}}{K_{\dot\theta}}\,\frac{1}{(\tau_{\dot\theta}s + 1)} \tag{C-23}$$

Using approximate expressions:

$$\frac{n_z(s)}{\dot{\theta}(s)} \cong \frac{V}{g} \frac{1}{\left(\frac{1}{L_\alpha} s+1\right)} \tag{C-24}$$

Similarly:

$$\frac{\dot{\gamma}(s)}{\dot{\theta}(s)} = \frac{1}{\left(\frac{1}{L_\alpha} s+1\right)} \tag{C-25}$$

$$\frac{\alpha(s)}{\dot{\theta}(s)} \cong \frac{1}{L_\alpha} \frac{1}{\left(\frac{1}{L_\alpha} s+1\right)} \tag{C-26}$$

$$\frac{\dot{\gamma}(s)}{\alpha(s)} \cong L_\alpha \tag{C-27}$$

$$\frac{n_z(s)}{\alpha(s)} \cong \frac{V}{g} L_\alpha \tag{C-28}$$

$$\frac{\dot{h}(s)}{n_z(s)} \cong \frac{g}{s} \tag{C-29}$$

$$\frac{\dot{h}(s)}{\dot{\gamma}(s)} \cong V \tag{C-30}$$

C.2 VERTICAL GUST INPUT

Consider the following equations of motion which assume constant speed, fixed controls, and gust inputs proportional to M_α and L_α only.

$$\ddot{\theta} - M_q \dot{\theta} - M_\alpha \alpha - M_{\dot{\alpha}} \dot{\alpha} = \frac{1}{V} M_\alpha w_{a.g.} \tag{C-31}$$

$$\dot{\alpha} - \dot{\theta} + L_\alpha \alpha = -\frac{1}{V} L_\alpha w_{a.g.} \tag{C-32}$$

The following transfer functions arise from Equations C-31 and C-32:

$$\frac{\theta(s)}{w_{a.g.}(s)} = \frac{M_\alpha - L_\alpha M_{\dot{\alpha}}}{V\omega_n^2} \frac{1}{\left[\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n} s+1\right]} \tag{C-33}$$

$$\frac{\alpha(s)}{w_{a.g.}(s)} = -\frac{1}{V} \frac{\left[\frac{L_\alpha}{\omega_n^2} s+1\right]}{\left[\frac{s^2}{\omega_n^2} + \frac{2\zeta}{\omega_n} s+1\right]} \tag{C-34}$$

$$\frac{n_z(s)}{w_{a.g.}(s)} = \frac{L_\alpha}{g} \frac{s\left[s-(M_q+M_{\dot{\alpha}})\right]}{\left[s^2+2\zeta\omega_n s+\omega_n^2\right]} \tag{C-35}$$

APPENDIX D

ADDITIONAL TRANSFER FUNCTION INFORMATION AND TABULATED DATA

D.1 TRANSFER FUNCTION DATA

A set of transformed equations of motion are developed in equations II-198 on page II-33 of Reference 9. Transfer function expressions for u/δ_e, w/δ_e, and θ/δ_e are developed on page II-34 of Reference 9 based on Equations II-198. The dimensional derivatives defined in Reference 9 are valid for linearized equations and small disturbances about the reference condition. These dimensional derivative definitions can be related to the nonlinear analog equations of Appendix A for trimmed level flight as indicated by the following expressions.

$$X_{\dot{w}} = X_q = X_{\delta_e} = Z_{\dot{w}} = Z_q = M_u = T_u = T_{\delta_{RPM}} = \gamma_0 = 0$$

$$X_u = -\frac{\rho S V}{m}\left(C_D + C_{D_u}\right) = -\frac{2(q_0 S C_{D_0})}{mV} = -\frac{2(948)}{399V} = -\frac{4.74}{V}$$

$$X_w = \frac{\rho S V}{m}\left(C_L - C_{D_\alpha}\right) = \frac{q_0 S}{mV}\left(C_{L_0} - C_{D_\alpha}\right) = \frac{g}{V}\left[1 - \frac{57.3(72.2)}{12{,}840}\right] = .678\,\frac{g}{V}$$

$$Z_u = -\frac{\rho S V}{2m}\left(C_L + C_{L_u}\right) = -\frac{2(q_0 S C_{L_0})}{mV} = -\frac{2g}{V}$$

$$Z_w = -\frac{\rho S V}{2m}\left(C_{L_\alpha} + C_D\right) = -L_\alpha$$

$$Z_{\delta_e} = -V L_\delta \quad \text{(See Table D-2 for value of } Z_{\delta_e}\text{)}$$

$$\left.\begin{aligned} M_w &= \frac{1}{V} M_\alpha \\ M_{\dot{w}} &= \frac{1}{V} M_{\dot{\alpha}} \\ M_q &= \frac{\rho S V c^2}{4 I_{YY}}\, C_{m_q} \end{aligned}\right\} \quad \text{(See Table D-2)}$$

$$M_{\delta_e} = \frac{\rho V^2 S c}{2 I_{YY}}\, C_{m_{\delta_e}} = -13.3$$

The numerical value of each dimensional derivative for each configuration evaluated is listed in Table D-2. It should be noted that positive elevator is defined as trailing edge down in this report rather than trailing edge up as in Reference 9.

Numerical values for the numerator and denominator factors of the transfer functions were solved using a digital computer. The transfer functions in factored form are listed below and the numerical values of the various factors are listed in Table D-3 for each configuration.

$$\frac{u(s)}{\delta_e(s)} = \frac{K_u}{K_{D_1}} \frac{(\tau_{u_1} s+1)(\tau_{u_2} s+1)}{\Delta}$$

$$\frac{\alpha(s)}{\delta_e(s)} = \frac{1}{V}\frac{w(s)}{\delta_e(s)} = \frac{K_w}{VK_{D_1}} \frac{(\tau_w s+1)\left(\frac{s^2}{\omega_{n_1}^2}+\frac{2\zeta_1}{\omega_{n_1}} s+1\right)}{\Delta}$$

$$\frac{\theta(s)}{\delta_e(s)} = \frac{K_\theta}{K_{D_1}} \frac{(\tau_{\theta_1} s+1)(\tau_{\theta_2} s+1)}{\Delta}$$

$$= \frac{K_\theta}{K_{D_1}} \frac{\left(\frac{s^2}{\omega_{n_2}^2}+\frac{2\zeta_2}{\omega_{n_2}} s+1\right)}{\Delta}$$

where $$\Delta \equiv \left(\frac{s^2}{\omega_{n_p}^2}+\frac{2\zeta_p}{\omega_{n_p}} s+1\right)\left(\frac{s^2}{\omega_{n_{sp}}^2}+\frac{2\zeta_{sp}}{\omega_{n_{sp}}} s+1\right)$$

D.2 TABULATED DATA

Table D-1 defines the short hand code used to identify the configurations or combinations of the independent variables [V, L_α , and short period] that were tested.

TABLE D-1

CODE

x x x

Code Number	Velocity knots
0	130
1	250
2	430
3	700
4	1100
5	1800

Code Number	L_α
1	.07
2	.15
3	.50
4	1.8
5	4.0

Code Number	Short Period	
	Freq. cps	Damping Ratio
1	.7	.7
2	.7	.3
4	.3	.3

Table D-4 lists the specific configurations evaluated by each pilot both by short hand code and by run number. This table also lists the pilot ratings and the stick to elevator gains selected as optimum by each pilot for each configuration evaluated. In some cases the stick to elevator gain was not determined because of equipment calibration difficulties.

The optimum stick to elevator gains selected by the pilots were used to calculate steady state gains for α / δ_{ES} , $\dot{\theta} / \delta_{ES}$ and n_z / δ_{ES} using the following definitions. See Appendix C.

$$\frac{\alpha}{\delta_{ES}} = \frac{\delta_e}{\delta_{ES}} \frac{M_\delta + M_q L_\delta}{\omega_n^2}$$

$$\frac{\dot{\theta}}{\delta_{ES}} = \frac{\delta_e}{\delta_{ES}} \frac{M_\delta L_\alpha - M_\alpha L_\delta}{\omega_n^2}$$

$$\frac{n_z}{\delta_{ES}} = \frac{\delta_e}{\delta_{ES}} \frac{V}{g} \frac{M_\delta L_\alpha - M_\alpha L_\delta}{\omega_n^2}$$

Code	X_u	X_w	Z_u	Z_w	Z_{δ_e}	M_w	$M_{\dot{w}}$	M_q	M_{δ_e}
024	-.0216	.0997	-.294	-.15	-1.17	-.0155	-.000128	-.950	-13.3
034	↓	↓	↓	-.50	-3.89	-.0148	↓	-.600	↓
044	↓	↓	↓	-1.8	-14.6	-.0219	↓	.700	↓
121	-.0112	.0517	-.153	-.15	-2.16	-.0438	-.0000664	-5.98	↓
131	↓	↓	↓	-.50	-7.25	-.0392	↓	-5.63	↓
141	↓	↓	↓	-1.8	-26.4	-.0274	↓	-4.33	↓
151	↓	↓	↓	-4.0	-58.8	-.0257	↓	-2.13	↓
122	↓	↓	↓	-.15	-2.16	-.0450	↓	-2.46	↓
132	↓	↓	↓	-.50	-7.21	-.0434	↓	-2.11	↓
142	↓	↓	↓	-1.8	-26.0	-.0424	↓	-.812	↓
152	↓	↓	↓	-4.0	-56.7	-.0590	↓	1.39	↓
124	↓	↓	↓	-.15	-2.25	-.00804	↓	-.950	↓
134	↓	↓	↓	-.50	-7.50	-.00766	↓	-.600	↓
144	↓	↓	↓	-1.8	-26.9	-.0114	↓	.700	↓
154	↓	↓	↓	-4.0	-58.2	-.0359	↓	2.90	↓
154A	↓	↓	↓	-4.0	-58.2	-.000781	.00870	-.800	↓
221	-.00654	.0301	-.0888	-.15	-3.71	-.0255	-.0000386	-5.98	↓
231	↓	↓	↓	-.50	-12.4	-.0228	↓	-5.63	↓
241	↓	↓	↓	-1.8	-45.4	-.0159	↓	-4.33	↓
251	↓	↓	↓	-4.0	-101	-.0149	↓	-2.13	↓
222	↓	↓	↓	-.15	-3.71	-.0262	↓	-2.46	↓
232	↓	↓	↓	-.50	-12.4	-.0252	↓	-2.11	↓
242	↓	↓	↓	-1.8	-44.6	-.0247	↓	-.812	↓
252	↓	↓	↓	-4.0	-97.5	-.0344	↓	1.39	↓
252A	↓	↓	↓	-4.0	-97.5	-.0223	.00298	-.800	↓
224	↓	↓	↓	-.15	-3.86	-.00468	-.0000386	-.950	↓
234	↓	↓	↓	-.50	-12.9	-.00454	↓	-.600	↓
244	↓	↓	↓	-1.8	-46.2	-.00661	↓	.700	↓
254	↓	↓	↓	-4.0	-99.9	-.0209	↓	2.90	↓
254A	↓	↓	↓	-4.0	-99.9	-.000455	.00506	-.800	↓
321	-.00402	.0185	-.0546	-.15	-6.05	-.0156	-.0000237	-5.98	↓
331	↓	↓	↓	-.50	-20.2	-.0140	↓	-5.63	↓
341	↓	↓	↓	-1.8	-61.6	-.00980	↓	-4.33	↓
351	↓	↓	↓	-4.0	-164	-.00918	↓	-2.13	↓
322	↓	↓	↓	-.15	-6.04	-.0161	↓	-2.46	↓
332	↓	↓	↓	-.50	-20.2	-.0155	↓	-2.12	↓
342	↓	↓	↓	-1.8	-72.7	-.0152	↓	-.812	↓
352	↓	↓	↓	-4.0	-159	-.0137	.00183	-.800	↓
324	↓	↓	↓	-.15	-6.29	-.00287	-.0000237	-.950	↓
334	↓	↓	↓	-.50	-21.0	-.00274	↓	-.600	↓
344	↓	↓	↓	-1.8	-75.2	-.00172	.00131	-.800	↓
354	↓	↓	↓	-4.0	-163	-.0128	-.0000237	2.90	↓
354A	↓	↓	↓	-4.0	-163	-.000280	.00311	-.800	↓
421	-.00255	.0118	-.0347	-.15	-9.51	-.00994	-.0000151	-5.98	↓
431	↓	↓	↓	-.50	-31.9	-.00890	↓	-5.63	↓
441	↓	↓	↓	-1.8	-116	-.00622	↓	-4.33	↓
451	↓	↓	↓	-4.0	-259	-.00583	↓	-2.13	↓
422	↓	↓	↓	-.15	-9.51	-.0102	↓	-2.46	↓
432	↓	↓	↓	-.50	-31.8	-.00985	↓	-2.12	↓
442	↓	↓	↓	-1.8	-114	-.00963	↓	-.812	↓
452	↓	↓	↓	-4.0	-250	-.00870	.00116	-.800	↓
424	↓	↓	↓	-.15	-9.90	-.00183	-.0000151	-.950	↓
434	↓	↓	↓	-.50	-33.0	-.00174	↓	-.600	↓
444	↓	↓	↓	-1.8	-118	-.00109	.000834	-.800	↓
454	↓	↓	↓	-4.0	-256	-.000178	.00198	-.800	↓
511	-.00156	.00718	-.0212	-.07	-7.27	-.00623	-.00000921	-6.06	↓
521	↓	↓	↓	-.15	-15.6	-.00607	↓	-5.98	↓
531	↓	↓	↓	-.50	-52.2	-.00544	↓	-5.63	↓
541	↓	↓	↓	-1.8	-193	-.00380	↓	-4.33	↓
512	↓	↓	↓	-.07	-7.27	-.00631	↓	-2.54	↓
522	↓	↓	↓	-.15	-15.6	-.00625	↓	-2.46	↓
532	↓	↓	↓	-.50	-52.0	-.00602	↓	-2.11	↓
542	↓	↓	↓	-1.8	-190	-.00586	↓	-.812	↓
514	↓	↓	↓	-.07	-7.57	-.00114	↓	-1.03	↓
524	↓	↓	↓	-.15	-16.2	-.00112	↓	-.950	↓
534	↓	↓	↓	-.50	-54.1	-.00106	↓	-.600	↓
544	↓	↓	↓	-1.8	-195	-.000668	.000510	-.800	↓

TABLE D-2 STABILITY DERIVATIVES IN THE EXPERIMENT

Code	ω_{n_p}	ζ_p	$\omega_{n_{SP}}$	ζ_{SP}	$\frac{K_u}{K_{D_1}}$	$\frac{1}{\tau_{u_1}}$	$\frac{1}{\tau_{u_2}}$	$\frac{K_w}{VK_{D_1}}$	$\frac{1}{\tau_w}$	ω_{n_1}	ζ_1	$\frac{K_\theta}{K_{D_1}}$	$\frac{1}{\tau_{\theta_1}}$	$\frac{1}{\tau_{\theta_2}}$	ω_{n_2}
024	.204	.0406	1.88	.302	434	-.462	1180	-3.92	-2500	.208	.0520	-2.95			.180
034	.199	.0358	1.88	.302	1520	-1.54	356	-4.11	- 749	.208	.0519	-3.81	-.0948	-.423	
044	.242	-.00611	1.88	.307	3670	-5.20	101	-2.77	- 199	.208	.0514	-4.35	-.0385	-1.76	
121	.105	.0482	4.40	.700	285	-.446	1230	-.720	-2600	.108	.0521	-.588			.0975
131	.0997	.0520	4.40	.700	1060	-1.50	364	-.804	- 780	.108	.0522	-.916	-.0288	-.461	
141	.0834	.0647	4.40	.700	5550	-5.37	102	-1.15	- 217	.107	.0523	-2.72	-.0159	-1.74	
151	.0807	.0622	4.40	.700	13200	-10.2	53.4	-1.23	-97.5	.107	.0521	-5.43	-.0133	-3.89	
122	.107	.0500	4.40	.300	276	-.444	1230	-.700	-2600	.108	.0520	-.571			.0975
132	.105	.0505	4.40	.300	957	-1.48	369	-.726	- 780	.108	.0520	-.826	-.0289	-.459	
142	.104	.0487	4.40	.300	3530	-5.12	107	-.743	- 217	.108	.0519	-1.73	-.0159	-1.71	
152	.122	.0353	4.40	.300	5530	-9.46	57.8	-.534	-97.6	.109	.0511	-2.29	-.0133	-3.75	
124	.106	.0467	1.88	.300	1610	-.462	1180	-3.92	-2500	.108	.0520	-3.22			.0978
134	.103	.0448	1.88	.300	5640	-1.54	356	-4.11	- 749	.108	.0520	-4.75	-.0281	-.479	
144	.126	.0186	1.88	.302	13600	-5.21	105	-2.77	- 208	.108	.0517	-6.63	-.0157	-1.77	
154	.224	-.0257	1.88	.307	9340	-9.41	58.1	-.879	-93.6	.110	.0507	-3.85	-.0133	-3.84	
154A	.0329	.00851	1.88	.303	445000	-9.49	59.9	-40.3	-97.3	.107	.0517	-183	-.0132	-3.85	
221	.0613	.0503	4.40	.700	840	-.446	1230	-.720	-2600	.0627	.0521	-.659	-.0303	-.119	
231	.0581	.0538	4.40	.700	3140	-1.50	364	-.804	- 780	.0626	.0522	-1.18	-.0123	-.473	
241	.0485	.0658	4.40	.700	16400	-5.37	102	-1.15	- 217	.0622	.0524	-4.11	-.00808	-1.74	
251	.0470	.0653	4.40	.700	38900	-10.2	53.4	-1.23	-97.6	.0621	.0523	-8.74	-.00723	-3.89	
222	.0622	.0511	4.40	.300	816	-.444	1230	-.700	-2600	.0628	.0521	- 640	-.0303	-.119	
232	.0611	.0518	4.40	.300	2830	-1.48	369	-.727	- 780	.0627	.0521	-1.07	-.0123	-.471	
242	.0604	.0510	4.40	.300	10400	-5.12	107	-.743	- 217	.0627	.0520	-2.62	-.00810	-1.72	
252	.0713	.0397	4.40	.300	16300	-9.46	57.8	-.534	-97.6	.0633	.0514	-3.68	-.00725	-3.75	
252A	.0574	.0502	4.40	.300	25800	-9.51	58.9	-.823	-99.7	.0626	.0519	-5.79	-.00724	-3.75	
224	.0615	.0494	1.88	.300	4760	-.462	1180	-3.92	-2500	.0628	.0520	-3.62	-.0289	-.126	
234	.0601	.0489	1.90	.298	16300	-1.54	356	-4.04	- 749	.0628	.0520	-6.05	-.0121	-.490	
244	.0732	.0296	1.88	.300	40200	-5.21	105	-2.77	- 208	.0629	.0518	-10.0	-.00805	-1.78	
254	.130	-.00407	1.88	.302	27600	-9.41	58.1	-.879	-93.6	.0638	.0509	-6.19	-.00724	-3.84	
254A	.0192	.0761	1.88	.301	1310000	-9.49	59.9	-40.3	-97.3	.0626	.0519	-294	-.00721	-3.85	
321	.0377	.0515	4.40	.700	2230	-.446	1230	-.720	-2600	.0385	.0521	-.766	-.0117	-.135	
331	.0357	.0548	4.40	.700	8320	-1.50	364	-.804	- 780	.0385	.0522	-1.58	-.00615	-.477	
341	.0298	.0664	4.40	.700	43600	-5.40	122	-1.15	- 259	.0383	.0524	-6.23	-.00459	-1.75	
351	.0289	.0669	4.40	.700	103000	-10.2	53.4	-1.23	-97.6	.0382	.0524	-13.7	-.00428	-3.89	
322	.0382	.0517	4.40	.300	2160	-.444	1230	-.700	-2600	.0386	.0521	-.744	-.0117	-.135	
332	.0375	.0525	4.40	.300	7480	-1.48	369	-.726	- 780	.0385	.0521	-1.43	-.00616	-.474	
342	.0371	.0522	4.40	.300	27600	-5.12	107	-.743	- 217	.0385	.0521	-3.95	-.00461	-1.72	
352	.0353	.0528	4.40	.300	68300	-9.51	58.9	-.823	-99.7	.0384	.0521	-9.07	-.00428	-3.75	
324	.0378	.0508	1.88	.300	12600	-.462	1180	-3.92	-2500	.0386	.0520	-4.23	-.0114	-.141	
334	.0369	.0510	1.88	.300	44100	-1.54	356	-4.11	- 749	.0386	.0520	-8.29	-.00608	-.494	
344	.0295	.0562	1.86	.282	254000	-5.21	106	-6.55	- 209	.0385	.0521	-36.1	-.00458	-1.78	
354	.0799	.00726	1.88	.301	73000	-9.41	58.1	-.879	-93.6	.0392	.0510	-9.70	-.00428	-3.84	
354A	.0118	.112	1.88	.301	3480000	-9.49	59.9	-40.3	-97.3	.0384	.0521	-462	-.00427	-3.85	
421	.0239	.0521	4.40	.700	5520	-.446	1230	-.720	-2600	.0245	.0521	-.925	-.00552	-.140	
431	.0227	.0553	4.40	.700	20600	-1.50	364	-.804	- 780	.0244	.0522	-2.18	-.00341	-.478	
441	.0189	.0668	4.40	.700	108000	-5.37	102	-1.15	- 217	.0243	.0525	-9.30	-.00278	-1.75	
451	.0183	.0679	4.40	.700	256000	-10.2	53.4	-1.23	-97.5	.0242	.0525	-21.1	-.00266	-3.89	
422	.0243	.0520	4.40	.300	5360	-.444	1230	-.700	-2600	.0245	.0521	-.899	-.00552	-.140	
432	.0238	.0529	4.40	.300	18600	-1.48	369	-.726	- 780	.0245	.0521	-1.96	-.00341	-.476	
442	.0236	.0529	4.40	.300	68400	-5.12	107	-.743	- 2.17	.0245	.0521	-5.92	-.00279	-1.72	
452	.0224	.0543	4.40	.300	169000	-9.51	58.9	-.823	-99.8	.0244	.0521	-14.0	-.00266	-3.75	
424	.0240	.0517	1.88	.300	31200	-.462	1180	-3.92	-2500	.0245	.0520	-5.13	-.00539	-.146	
434	.0234	.0522	1.88	.300	109000	-1.54	356	-4.11	- 749	.0245	.0520	-11.4	-.00338	-.495	
444	.0187	.0605	1.86	.282	629000	-5.21	106	-6.55	- 209	.0245	.0521	-54.2	-.00278	-1.78	
454	.00749	.133	1.88	.301	8630000	-9.49	59.9	-40.3	-97.3	.0244	.0521	-711	-.00265	-3.85	
511	.0148	.0519	4.40	.700	6710	-.207	2640	-.702	-5570	.0150	.0521	-.801	-.00399	-.0642	
521	.0146	.0526	4.40	.700	14800	-.446	1230	-.721	-2600	.0150	.0521	-1.21	-.00264	-.142	
531	.0138	.0557	4.40	.700	55200	-1.50	364	-.804	- 780	.0149	.0522	-3.22	-.00188	-.478	
541	.0116	.0670	4.40	.700	288000	-5.37	101	-1.15	- 214	.0148	.0525	-14.7	-.00165	-1.75	
512	.0149	.0519	4.40	.300	6620	-.207	2640	-.694	-5570	.0150	.0520	-.791	-.00399	-.0641	
522	.0148	.0522	4.40	.300	14300	-.444	1230	-.701	-2600	.0150	.0521	-1.17	-.00265	-.142	
532	.0146	.0531	4.40	.300	49700	-1.48	369	-.726	- 780	.0150	.0521	-2.90	-.00188	-.476	
542	.0144	.0534	4.40	.300	183000	-5.11	105	-.743	- 214	.0150	.0521	-9.36	-.00165	-1.72	
514	.0148	.0518	1.88	.300	38200	-.215	2540	-3.84	-5340	.0150	.0520	-4.45	-.00388	-.0670	
524	.0147	.0522	1.88	.300	83600	-.462	1180	-3.92	-2500	.0150	.0520	-6.71	-.00260	-.148	
534	.0143	.0531	1.88	.300	293000	-1.54	356	-4.11	- 749	.0150	.0520	-17.0	-.00187	-.495	
544	.0115	.0635	1.86	.282	1680000	-5.21	105	-6.55	- 208	.0150	.0521	-85.9	-.00164	-1.78	

TABLE D-3 TRANSFER FUNCTION FACTORS

p	ζ_D	$\omega_{n_{SP}}$	ζ_{SP}	$\frac{K_u}{K_{D_1}}$	$\frac{1}{\tau_{u_1}}$	$\frac{1}{\tau_{u_2}}$	$\frac{K_w}{VK_{D_1}}$	$\frac{1}{\tau_w}$	ω_{n_1}	ζ_1	$\frac{K_\theta}{K_{D_1}}$	$\frac{1}{\tau_{\theta_1}}$	$\frac{1}{\tau_{\theta_2}}$	ω_{n_2}	ζ_2	$\frac{K_{\theta_{STATIC}}}{K_{\theta_{SP}}}$	$\frac{L_\alpha V}{g}$
04	.0406	1.88	.302	434	-.462	1180	-3.92	-2500	.208	.0520	-2.95			.180	.472	.779	1.03
99	.0358	1.88	.302	1520	-1.54	356	-4.11	- 749	.208	.0519	-3.81	-.0948	-.423			1.01	3.42
42	-.00611	1.88	.307	3670	-5.20	101	-2.77	- 199	.208	.0514	-4.35	-.0385	-1.76			1.16	12.3
05	.0482	4.40	.700	285	-.446	1230	-.720	-2600	.108	.0521	-.588			.0975	.791	.862	1.97
997	.0520	4.40	.700	1060	-1.50	364	-.804	- 780	.108	.0522	-.916	-.0288	-.461			1.34	6.55
834	.0647	4.40	.700	5550	-5.37	102	-1.15	- 217	.107	.0523	-2.72	-.0159	-1.74			3.95	23.6
807	.0622	4.40	.700	13200	-10.2	53.4	-1.23	-97.5	.107	.0521	-5.43	-.0133	-3.89			7.94	52.4
07	.0500	4.40	.300	276	-.444	1230	-.700	-2600	.108	.0520	-.571			.0975	.790	.830	1.97
05	.0505	4.40	.300	957	-1.48	369	-.726	- 780	.108	.0520	-.826	-.0289	-.459			1.20	6.55
04	.0487	4.40	.300	3530	-5.12	107	-.743	- 217	.108	.0519	-1.73	-.0159	-1.71			2.51	23.6
22	.0353	4.40	.300	5530	-9.46	57.8	-.534	-97.6	.109	.0511	-2.29	-.0133	-3.75			3.35	52.4
06	.0467	1.88	.300	1610	-.462	1180	-3.92	-2500	.108	.0520	-3.22			.0978	.817	.851	1.97
03	.0448	1.88	.300	5640	-1.54	356	-4.11	- 749	.108	.0520	-4.75	-.0281	-.479			1.06	6.55
26	.0186	1.88	.302	13600	-5.21	105	-2.77	- 208	.108	.0517	-6.63	-.0157	-1.77			1.75	23.6
24	-.0257	1.88	.307	9340	-9.41	58.1	-.879	-93.6	.110	.0507	-3.85	-.0133	-3.84			.498	52.4
329	.00851	1.88	.303	445000	-9.49	59.9	-40.3	-97.3	.107	.0517	-183	-.0132	-3.85			22.9	52.4
613	.0503	4.40	.700	840	-.446	1230	-.720	-2600	.0627	.0521	-.659	-.0303	-.119			.960	3.38
581	.0538	4.40	.700	3140	-1.50	364	-.804	- 780	.0626	.0522	-1.18	-.0123	-.473			1.72	11.3
485	.0658	4.40	.700	16400	-5.37	102	-1.15	- 217	.0622	.0524	-4.11	-.00808	-1.74			5.98	40.6
470	.0653	4.40	.700	38900	-10.2	53.4	-1.23	-97.6	.0621	.0523	-8.74	-.00723	-3.89			12.7	90.1
622	.0511	4.40	.300	816	-.444	1230	-.700	-2600	.0628	.0521	- 640	-.0303	-.119			.932	3.38
611	.0518	4.40	.300	2830	-1.48	369	-.727	- 780	.0627	.0521	-1.07	-.0123	-.471			1.55	11.3
604	.0510	4.40	.300	10400	-5.12	107	-.743	- 217	.0627	.0520	-2.62	-.00810	-1.72			3.82	40.6
713	.0397	4.40	.300	16300	-9.46	57.8	-.534	-97.6	.0633	.0514	-3.68	-.00725	-3.75			5.35	90.1
574	.0502	4.40	.300	25800	-9.51	58.9	-.823	-99.7	.0626	.0519	-5.79	-.00724	-3.75			8.24	90.1
615	.0494	1.88	.300	4760	-.462	1180	-3.92	-2500	.0628	.0520	-3.62	-.0289	-.126			.963	3.38
601	.0489	1.90	.298	16300	-1.54	356	-4.04	- 749	.0628	.0520	-6.05	-.0121	-.490			1.64	11.3
732	.0296	1.88	.300	40200	-5.21	105	-2.77	- 208	.0629	.0518	-10.0	-.00805	-1.78			2.67	40.6
30	-.00407	1.88	.302	27600	-9.41	58.1	-.879	-93.6	.0638	.0509	-6.19	-.00724	-3.84			.805	90.1
192	.0761	1.88	.301	1310000	-9.49	59.9	-40.3	-97.3	.0626	.0519	-294	-.00721	-3.85			36.8	90.1
377	.0515	4.40	.700	2230	-.446	1230	-.720	-2600	.0385	.0521	-.766	-.0117	-.135			1.11	5.50
357	.0548	4.40	.700	8320	-1.50	364	-.804	- 780	.0385	.0522	-1.58	-.00615	-.477			2.30	18.3
298	.0664	4.40	.700	43600	-5.40	122	-1.15	- 259	.0383	.0524	-6.23	-.00459	-1.75			9.05	65.9
289	.0669	4.40	.700	103000	-10.2	53.4	-1.23	-97.6	.0382	.0524	-13.7	-.00428	-3.89			19.9	147
382	.0517	4.40	.300	2160	-.444	1230	-.700	-2600	.0386	.0521	-.744	-.0117	-.135			1.08	5.50
375	.0525	4.40	.300	7480	-1.48	369	-.726	- 780	.0385	.0521	-1.43	-.00616	-.474			2.08	18.3
371	.0522	4.40	.300	27600	-5.12	107	-.743	- 217	.0385	.0521	-3.95	-.00461	-1.72			5.76	65.9
353	.0528	4.40	.300	68300	-9.51	58.9	-.823	-99.7	.0384	.0521	-9.07	-.00428	-3.75			12.9	147
378	.0508	1.88	.300	12600	-.462	1180	-3.92	-2500	.0386	.0520	-4.23	-.0114	-.141			1.12	5.50
369	.0510	1.88	.300	44100	-1.54	356	-4.11	- 749	.0386	.0520	-8.29	-.00608	-.494			2.21	18.3
295	.0562	1.86	.282	254000	-5.21	106	-6.55	- 209	.0385	.0521	-36.1	-.00458	-1.78			9.37	65.9
799	.00726	1.88	.301	73000	-9.41	58.1	-.879	-93.6	.0392	.0510	-9.70	-.00428	-3.84			1.26	147
118	.112	1.88	.301	3480000	-9.49	59.9	-40.3	-97.3	.0384	.0521	-462	-.00427	-3.85			57.6	147
239	.0521	4.40	.700	5520	-.446	1230	-.720	-2600	.0245	.0521	-.925	-.00552	-.140			1.35	8.64
227	.0553	4.40	.700	20600	-1.50	364	-.804	- 780	.0244	.0522	-2.18	-.00341	-.478			3.16	28.9
189	.0668	4.40	.700	108000	-5.37	102	-1.15	- 217	.0243	.0525	-9.30	-.00278	-1.75			13.6	104
183	.0679	4.40	.700	256000	-10.2	53.4	-1.23	-97.5	.0242	.0525	-21.1	-.00266	-3.89			30.9	231
243	.0520	4.40	.300	5360	-.444	1230	-.700	-2600	.0245	.0521	-.899	-.00552	-.140			1.31	8.64
238	.0529	4.40	.300	18600	-1.48	369	-.726	- 780	.0245	.0521	-1.96	-.00341	-.476			2.87	28.9
236	.0529	4.40	.300	68400	-5.12	107	-.743	- 2.17	.0245	.0521	-5.92	-.00279	-1.72			8.62	104
224	.0543	4.40	.300	169000	-9.51	58.9	-.823	-99.8	.0244	.0521	-14.0	-.00266	-3.75			20.0	231
240	.0517	1.88	.300	31200	-.462	1180	-3.92	-2500	.0245	.0520	-5.13	-.00539	-.146			1.37	8.64
234	.0522	1.88	.300	109000	-1.54	356	-4.11	- 749	.0245	.0520	-11.4	-.00338	-.495			3.06	28.9
187	.0605	1.86	.282	629000	-5.21	106	-6.55	- 209	.0245	.0521	-54.2	-.00278	-1.78			14.2	104
0749	.133	1.88	.301	8630000	-9.49	59.9	-40.3	-97.3	.0244	.0521	-711	-.00265	-3.85			88.8	231
148	.0519	4.40	.700	6710	-.207	2640	-.702	-5570	.0150	.0521	-.801	-.00399	-.0642			1.17	6.60
146	.0526	4.40	.700	14800	-.446	1230	-.721	-2600	.0150	.0521	-1.21	-.00264	-.142			1.75	14.2
138	.0557	4.40	.700	55200	-1.50	364	-.804	- 780	.0149	.0522	-3.22	-.00188	-.478			4.72	47.2
116	.0670	4.40	.700	288000	-5.37	101	-1.15	- 214	.0148	.0525	-14.7	-.00165	-1.75			21.5	170
149	.0519	4.40	.300	6620	-.207	2640	-.694	-5570	.0150	.0520	-.791	-.00399	-.0641			1.15	6.60
148	.0522	4.40	.300	14300	-.444	1230	-.701	-2600	.0150	.0521	-1.17	-.00265	-.142			1.72	14.2
146	.0531	4.40	.300	49700	-1.48	369	-.726	- 780	.0150	.0521	-2.90	-.00188	-.476			4.20	47.2
144	.0534	4.40	.300	183000	-5.11	105	-.743	- 214	.0150	.0521	-9.36	-.00165	-1.72			13.7	170
148	.0518	1.88	.300	38200	-.215	2540	-3.84	-5340	.0150	.0520	-4.45	-.00388	-.0670			1.19	6.60
147	.0522	1.88	.300	83600	-.462	1180	-3.92	-2500	.0150	.0520	-6.71	-.00260	-.148			1.78	14.2
143	.0531	1.88	.300	293000	-1.54	356	-4.11	- 749	.0150	.0520	-17.0	-.00187	-.495			4.53	47.2
115	.0635	1.86	.282	1680000	-5.21	105	-6.55	- 208	.0150	.0521	-85.9	-.00164	-1.78			22.1	170

TABLE D-3 TRANSFER FUNCTION FACTORS

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TABLE D-4 PILOT RATINGS AND O

Code	Config. No.	Pilot Rating: Smooth Air	Pilot Rating: Rough Air	$\frac{\delta_e}{\delta_{ES}}$	$\frac{\delta_e}{\delta_{ES}} K_\alpha$	$\frac{\delta_e}{\delta_{ES}} K_{\dot{\theta}}$	$\frac{\delta_e}{\delta_{ES}} K_{n_z}$	$\frac{L_\alpha V}{g}$
024	77	9.5	10	-.332	1.25	.186	1.26	1.03
034	78	7	8	-.332	1.25	.619	4.21	3.42
044	76	9	10	-.133	.501	.889	6.04	12.3
044	76A	8.5	10	-.133	.501	.889	6.04	12.3
121	4	4.5	5	-8.00	5.50	.786	10.3	1.97
131	3	2	2	-3.00	2.06	.986	12.9	6.55
141	15	3	4	-1.10	.756	1.32	17.3	23.6
151	7	3	5	-.75	.515	2.00	26.2	52.4
122	9	7.5	7.5	-2.00	1.37	.196	2.57	1.97
132	10	5	5	-2.00	1.37	.655	8.57	6.55
142	5	3.5	6	-1.00	.687	1.18	15.5	23.6
152	11	5	8	-.300	.206	.772	10.1	52.4
124	6	7	7	-1.50	5.64	.839	11.0	1.97
124	14	7	8.5	-.400	1.51	.224	2.93	1.97
124	12	7	7	-.300	1.13	.168	2.20	1.97
124	1	5	6	-.500	1.88	.280	3.67	1.97
134	8	4	4	-.500	1.88	.933	12.2	6.55
144	13	4.5	8	-.100	.376	.669	8.76	23.6
154	2	10	10	-.020	.0753	.289	3.79	52.4
154A	2A	9	10	-.020	.0753	.301	3.94	52.4
221	19	5	5	-2.25	1.55	.221	4.98	3.38
231	18	2	2.5	-3.25	2.23	1.07	24.1	11.3
241	16	3	5	-.900	.618	1.08	24.3	40.6
241	27	3	5	-.400	.275	.480	10.8	40.6
241	29	4.5	8	-.500	.344	.600	13.5	40.6
241	21	4.5	6	-.350	.241	.420	9.45	40.6
251	22	5	9	-.150	.103	.401	9.02	90.1
222	24	6	7	-1.50	1.03	.147	3.31	3.38
232	25	3	3	-1.50	1.03	.491	11.1	11.3
242	20	6	8.5	-.350	.241	.413	9.30	40.6
242	20A	3	7.5	-.400	.275	.472	10.6	40.6
252	26	2.5	10	-.150	.103	.386	8.70	90.1
252A	26A	3	9	-.150	.103	.386	8.70	90.1
224	30	7	7	-.400	1.51	.224	5.04	3.38
234	23	3.5	5	-.200	.763	.373	8.40	11.3
244	28	5	10	-.0400	.151	.268	6.03	40.6
254	17	8	10	–	–	–	–	90.1
254A	17A	9.5	10	–	–	–	–	90.1
321	34	5	5	-2.50	1.72	.246	9.00	5.50
331	33	2.5	3	-1.35	.928	.444	16.3	18.3
341	45	6	7.5	-.300	.206	.362	13.3	65.9
341	45A	6	7	-.200	.137	.241	8.84	65.9
351	37	4.5	8	-.150	.103	.401	14.7	147

D-4 PILOT RATINGS AND OPTIMUM LONGITUDINAL GAINS - PILOT A

$\frac{\delta_e}{\delta_{ES}} K_{\dot\theta}$	$\frac{\delta_e}{\delta_{ES}} K_{n_z}$	$\frac{L_\alpha V}{g}$
186	1.26	1.03
619	4.21	3.42
889	6.04	12.3
889	6.04	12.3
786	10.3	1.97
986	12.9	6.55
.32	17.3	23.6
.00	26.2	52.4
.196	2.57	1.97
.655	8.57	6.55
.18	15.5	23.6
.772	10.1	52.4
.839	11.0	1.97
.224	2.93	1.97
.168	2.20	1.97
.280	3.67	1.97
.933	12.2	6.55
.669	8.76	23.6
.289	3.79	52.4
.301	3.94	52.4
.221	4.98	3.38
.07	24.1	11.3
.08	24.3	40.6
.480	10.8	40.6
.600	13.5	40.6
.420	9.45	40.6
.401	9.02	90.1
.147	3.31	3.38
.491	11.1	11.3
.413	9.30	40.6
.472	10.6	40.6
.386	8.70	90.1
.386	8.70	90.1
.224	5.04	3.38
.373	8.40	11.3
.268	6.03	40.6
-	-	90.1
-	-	90.1
.246	9.00	5.50
.444	16.3	18.3
.362	13.3	65.9
.241	8.84	65.9
.401	14.7	147

Code	Config. No.	Pilot Rating Smooth Air	Pilot Rating Rough Air	$\frac{\delta_e}{\delta_{ES}}$	$\frac{\delta_e}{\delta_{ES}} K_\alpha$	$\frac{\delta_e}{\delta_{ES}} K_{\dot\theta}$	$\frac{\delta_e}{\delta_{ES}} K_{n_z}$	$\frac{L_\alpha V}{g}$
322	39	6.5	8	-2.00	1.37	.196	7.18	5.50
332	40	3	4	-1.25	.859	.409	15.0	18.3
342	31	3	5	-.300	.206	.354	13.0	65.9
342	36	4	7	-.350	.241	.413	15.1	65.9
342	42	3.5	7.5	-.200	.137	.236	8.64	65.9
342	44	4.5	7	-.200	.137	.236	8.64	65.9
352	41	5	10	-.100	.0687	.264	9.66	147
324	35	6	6	-.300	1.13	.168	6.15	5.50
334	38	5	5.5	-.150	.565	.280	10.3	18.3
344	43	7	9	-	-	-	-	65.9
354A	32	8	10	-	-	-	-	147
421	49	5	5	-1.75	1.20	.172	9.92	8.64
431	51	5	5	-.750	.515	.247	14.2	28.9
431	57	4	4	-.750	.515	.247	14.2	28.9
431	59	2	2.5	-.750	.515	.247	14.2	28.9
431	46	5	5	-.800	.550	.263	15.2	28.9
441	60	4	6	-.250	.172	.300	17.3	104
451	52	7.5	9.5	-.100	.0687	.267	15.4	231
422	54	3.5	3.5	-2.00	1.37	.196	11.3	8.64
432	55	3.5	3.5	-.500	.344	.164	9.45	28.9
442	50	5.5	7.5	-.150	.103	.177	10.2	104
452	56	6	10	-.100	.0687	.264	15.2	231
424	48	6.5	6.5	-.250	.941	.140	8.07	8.64
434	53	5.5	5.5	-.150	.565	.280	16.1	28.9
444	58	8	9.5	-.0270	.102	.182	10.5	104
454	47	9.5	10	-.0130	.0489	.196	11.3	231
511	64	6	6	-2.50	1.72	.114	10.8	6.60
521	63	5	5	-1.50	1.03	.147	13.9	14.2
531	75	6	6.5	-.400	.275	.132	12.4	47.2
541	67	5	8	-.0930	.0639	.112	10.5	170
512	69	6	6	-1.75	1.20	.0800	7.55	6.60
522	70	5	5	-1.25	.859	.123	11.6	14.2
532	65	3	-	-.300	.206	.0982	9.27	47.2
542	71	6.5	8.5	-.110	.0756	.130	12.2	170
514	61	6.5	6.5	-.500	1.88	.131	12.3	6.60
514	66	7	7	-.300	1.13	.0783	7.39	6.60
514	72	6.5	7.5	-.300	1.13	.0783	7.39	6.60
514	74	7	7	-.400	1.51	.104	9.86	6.60
524	68	4	4	-.200	.753	.112	10.6	14.2
534	73	6.5	7.5	-.0670	.252	.125	11.8	47.2
544	62	8	9.5	-.0130	.0489	.0876	8.27	170

$\frac{\delta_e}{\delta_{ES}} K_{n_z}$	$\frac{L_\alpha V}{g}$
1.52	1.03
5.06	3.42
12.1	12.3
5.14	1.97
12.9	6.55
9.43	23.6
14.0	52.4
17.5	52.4
2.57	1.97
7.51	6.55
7.73	23.6
15.5	23.6
6.75	52.4
2.93	1.97
3.67	1.97
2.93	1.97
6.60	1.97
9.78	6.55
8.77	23.6
14.2	52.4
9.86	52.4
7.74	3.38
22.2	11.3
13.5	40.6
18.9	40.6
18.9	40.6
21.6	40.6
18.0	90.1
4.41	3.38
9.21	11.3
13.3	40.6
23.2	90.1
6.30	3.38
12.6	11.3
15.1	40.6
-	-
-	-
8.99	5.50
15.1	18.3
8.83	65.9
14.7	147

PILOT RATINGS AND OPTIMUM LONGITUDINAL GAINS - PILOT B

Code	Config. No.	Pilot Rating		$\frac{\delta_e}{\delta_{ES}}$	$\frac{\delta_e}{\delta_{ES}} K_\alpha$	$\frac{\delta_e}{\delta_{ES}} K_{\dot\theta}$	$\frac{\delta_e}{\delta_{ES}} K_{n_z}$	$\frac{L_\alpha V}{g}$
		Smooth Air	Rough Air					
322	39	5	5	-2.50	1.72	.245	8.99	5.50
332	40	5	5	-1.50	1.03	.491	18.0	18.3
332	40A	3	3	-1.75	1.20	.573	21.0	18.3
342	36	3	-	-.500	.344	.590	21.6	65.9
342	42	3.5	5.5	-.350	.240	.413	15.1	65.9
342	31	2.5	8	-.400	.275	.472	17.3	65.9
342	44	3	8	-.400	.275	.472	17.3	65.9
352	41	4	9	-.150	.103	.395	14.5	147
324	35	6	6	-.500	1.88	.280	10.3	5.50
334	38	6	6	-.250	.941	.466	17.1	18.3
344	43	5.5	9.5	-.0500	.188	.337	12.3	65.9
354A	32	7	10	-	-	-	-	147
421	49	4	4	-2.50	1.72	.235	14.1	8.64
431	51	2	2	-1.25	.859	.411	23.7	28.9
431	57	5	5	-1.25	.859	.411	23.7	28.9
431	46	3	3	-.750	.515	.247	14.2	28.9
431	59	3.5	3.5	-1.25	.859	.411	23.7	28.9
441	60	4.5	6	-.350	.240	.420	24.2	104
451	52	7	9	-.233	.160	.622	35.9	231
422	54	6	6	-2.50	1.72	.245	14.1	8.64
432	55	4	4	-1.00	.687	.327	18.9	28.9
442	50	3	7	-.400	.275	.472	27.2	104
452	56	7.5	10	-.0665	.0457	.175	10.1	231
452	56A	6	10	-.0665	.0457	.175	10.1	231
424	48	5	5	-.400	1.51	.224	12.9	8.64
434	53	5	5.5	-.200	.753	.373	21.5	28.9
444	58	8.5	9.5	-.0266	.100	.179	10.3	104
444	58A	6.5	9.5	-.0399	.150	.269	15.5	104
454	47	8	10	-	-	-	-	231
511	64	4	4	-4.00	2.75	.183	17.3	6.60
521	63	3	3	-3.00	2.06	.294	27.8	14.2
531	75	3	3	-.750	.515	.247	23.3	47.2
541	67	5.5	8	-.150	.103	.180	17.0	170
512	69	8	8	-2.00	1.37	.0914	8.63	6.60
522	70	5	5	-2.50	1.72	.245	23.1	14.2
532	65	5	5	-.400	.275	.131	12.4	47.2
542	71	7	8.5	-.200	.137	.235	22.2	170
514	72	8	8	-.400	1.51	.104	9.86	6.60
514	74	7	7	-.400	1.51	.104	9.86	6.60
514	66	6	6	-.400	1.51	.104	9.86	6.60
514	61	8.5	8.5	-.600	2.26	.157	14.8	6.60
524	68	7	7	-.250	.941	.140	13.2	14.2
534	73	7	7.5	-.0998	.376	.186	17.6	47.2
544	62	8.5	10	-.0333	.125	.224	21.2	170

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TABLE D-4 PILOT RATINGS AND OPTIMUM LONGITUDINAL GAINS
PILOT C

Code	Config. No.	Pilot Rating Smooth Air	Pilot Rating Rough Air	$\frac{\delta_e}{\delta_{ES}}$	$\frac{\delta_e}{\delta_{ES}} K_\alpha$	$\frac{\delta_e}{\delta_{ES}} K_{\dot\theta}$	$\frac{\delta_e}{\delta_{ES}} K_{n_z}$	$\frac{L_\alpha V}{g}$
121	4	9	9	-5.00	3.44	.491	6.44	1.97
131	3	7	7	-4.00	2.75	1.32	17.2	6.55
131	3A	4	6.5	-4.50	3.09	1.48	19.4	6.55
141	15	2.5	4	-1.50	1.03	1.80	23.6	23.6
151	7	1.5	5	-.750	.515	2.00	26.2	52.4
222	24	8	8	-4.00	2.75	.392	8.83	3.38
232	25	5	5.5	-3.00	2.06	.982	22.1	11.3
242	20	3.5	7	-1.20	.824	1.42	31.9	40.6
252	26	2.5	10	-.400	.275	1.03	23.2	90.1
321	34	6	6	-4.00	2.75	.393	14.4	5.50
331	33	1.5	1.5	-2.25	1.55	.740	27.1	18.3
341	45	2	4	-.750	.515	.904	33.1	65.9
351	37	2.5	6	.250	.172	.668	24.5	147
324	35	7	7	-.800	3.01	.448	16.4	5.50
334	38	3	3	-.300	1.13	.560	20.5	18.3
344	43	2	8	-.0800	.301	.539	19.8	65.9
354	32	6	10	-.0300	.113	.451	16.5	147
354A	32A	9	10	-.0300	.113	.434	15.9	147
422	54	5	5	-2.50	1.72	.245	14.1	8.64
432	55	3	3	-1.00	.687	.327	18.9	28.9
442	50	2	5.5	-.400	.275	.472	27.2	104
452	56	2	10	-.150	.103	.395	22.8	231
511	64	5.5	5.5	-4.50	3.09	.206	19.4	6.60
521	63	4	4	-3.00	2.06	.295	27.8	14.2
531	75	3	3.5	-1.25	.859	.411	38.8	47.2
541	67	4.5	8	-.250	.172	.300	28.3	170

APPENDIX E

This appendix contains the comments of pilots A and B for a selected number of configurations together with the comments of pilot C for all of the configurations listed in Table 3 on page 19.

The verbatim comments have been included in this Appendix because it is believed that they contain sufficient information, in addition to that extracted for the summaries presented in the body of the report to make their inclusion a valuable supplement to the report. Through study of these comment data the reader can form an appreciation of the complexity of the flight control task from the pilot's point of view and gain some insight into the relative weighing of the various factors which influence the numerical rating assigned by the pilot.

The verbatim comment data have also been included as an example in support of the hypothesis that exploratory handling quality investigations should be designed to use pilot comments as one of the main sources of information.

The fact that such investigations are termed handling or flying quality investigations implies that the degree of acceptability of the vehicle to the pilot is of primary concern. Therefore, it seems logical to ask the pilot whether or not the vehicle is acceptable and if not, what factors are contributing to the unacceptability. Such comments have been found invaluable in developing an understanding of the relative importance of various vehicle characteristics to the general handling quality suitability of the vehicle.

Through pilot comments, in many cases the causes of control difficulty can be determined and the reasons for unsatisfactory ratings can be established directly rather than by implications from correlations.

The comment transcriptions which follow are identified by configuration number and can be related to the variables in the experiment through Tables 2 and 3 in the body of the report or Table D-4 in Appendix D.

PILOT A

CONFIGURATION 9 SMOOTH AIR 9 MARCH 1962

This configuration is difficult in trim, and applying control changes to the airplane does not necessarily mean that the airplane will respond to this attitude application change. For instance, if you are in a climb and you push over into a dive, the airplane still continues to climb for quite some time before it noses over and the same is true of a dive. It takes quite a bit of time to change the airplane's direction of flight. Consequently, it is very difficult to trim. It takes a lone time to trim for level flight. You never know where trim is on this airplane. Attitude control is far from satisfactory. It is definitely unsatisfactory. Very poor.

Normal acceleration control is not a problem at all. I saw very, very small acceleration excursions throughout this flight.

The elevator gear ratio - I selected something that was fairly high in an attempt to make the airplane respond to my control applications a little bit more quickly. Something lower than this just gave me heavy forces and worse control actually than I had with this gear ratio of 200 which I selected. I tried a higher gear ratio, but all this gave me was a lot of stick travel and my attitude changed position drastically, but the airplane did not respond. 200 was perhaps still a little high, but this airplane responds very, very slowly to control applications. I could hold altitude once I determined my trim, but it takes a long time to establish an altitude that you can trim out.

Turns are quite difficult. I recommend this airplane be limited to 30° turns. I tried 60° and I ran out of power almost immediately. So maintaining airspeed is a problem; it is a problem in pitch and in turns. It bleeds off quite rapidly in a climb and when you pitch over it does not recover immediately.

Special piloting technique required? This airplane has a lot of lag between control applications and change of flight path. This has to be taken into account. All your maneuvers would have to be planned for in advance and control application would have to be applied in advance of the time when you needed the change of flight path.

I don't think any other instruments would particularly help the pilot here. It is just that the airplane is so highly damped apparently that it just won't change flight path normally. When it does change, however, you have some difficulty stopping the rate of motion and restabilizing the aircraft.

It is an airplane that can be flown. It doesn't have any high rates of pitch change so you can recover. It is an aircraft that responds to control application so poorly that I am going to rate it 7.5 on the numerical rating scale.

PILOT A
CONFIGURATION 9, ROUGH AIR, 9 MARCH 1962

Rough air has very little effect on this configuration. It may move attitude gyro, but it doesn't move the airplane very much. The altitude more or less stays where it is even though the rate of climb fluctuates. Airspeed doesn't change at all. g units doesn't change at all. Angle of attack changes a little bit. But in general, although there are forces applied to the airplane, the airplane attitude doesn't change very much. Rough air has no effect on it. There is no change in the rating - 7.5. I could fly it in rough air indefinitely. Maneuverability is still the problem with this airplane. That's why I gave it such a low rating. It is not dangerous, it's just that the maneuverability is very poor. So it is a 7.5 rating airplane, both rough and smooth air.

PILOT A
CONFIGURATION 11, SMOOTH AIR, 14 MARCH 1962

This airplane trimmed up fairly well in straight and level flight, but I had difficulty in trimming up during descents, climbs, and turns. It seems that I had difficulty in establishing a rate of climb or descent and holding it. This may be something that is inherent in the simulator and may have nothing to do with the configuration, but it is there; it is annoying.

I am unable to do precise descents or climbs either while flying straight or turns.

So attitude control is satisfactory, straight and level flight, but it is not satisfactory during maneuvers.

Normal acceleration has to be watched here. I saw indicator excursions of ±1g during maneuvers, and this would be rather uncomfortable for a pilot, certainly uncomfortable for passengers or crew.

I picked an elevator gear ratio that was a little low, so I would have a little g-limiting protection. It still has to be flown carefully or you go through the ±1g excursions. I think I had 30 on my elevator gear ratio.

I can hold altitude straight and level, but it is difficult in turns. You can use up to 60° in this airplane as far as bank angle is concerned, but at that angle you have difficulty in maintaining altitude, 45° was much better. At 45° I found that the airplane was much easier to fly. At 30° I did a fairly good job of holding altitude.

Airspeed is not a great problem. It has to be watched, but it is not a really difficult problem.

No particularly special piloting technique is required.

I am using normal instruments. I don't know that any improvement on instrumentation is necessary.

In general, it is a kind of configuration that has just fair handling qualities. It is not dangerous in any sense of the word, but it is not a good stable airplane. Control and handling qualities are such that the pilot cannot do a completely precise job of flying and he has to work at it constantly. He becomes annoyed with himself for not being able to hold his values a little better. So I am going to rate this airplane a 5.5. I am checking my rating scale again. I think 5 would be a better rating than 5.5, so I am changing my rating back to 5.

PILOT A
CONFIGURATION 11, ROUGH AIR, 14 MARCH 1962

On this configuration, the pilot was able to do a fair job of holding attitude and altitude, airspeed, etc. But the excursions of his accelerometer were ±1g. Now this is pretty high and if the pilot were actually subjected to these accelerations, undoubtedly it would affect his well-being and his ability to fly this airplane. I think it would be a pretty tough airplane to fly for a half hour because your body would be subjected to these accelerations which would increase the fatigue factor, etc. The airplane, I think, is quite bad under rough air conditions, much worse than under smooth air. I am going to have to rate it an 8 on the rating scale. The primary reason I am giving it such a high rating are the excursions of the accelerometer which indicate to me that the pilot would be subjected to this g and it would definitely affect his ability to be able to stay with this airplane and to fly it precisely for any length of time. He would be in a bad situation here. He could probably last for a half hour, but after that the fatigue factor would develop rapidly.

PILOT A
CONFIGURATION 35, SMOOTH AIR, 29 MARCH 1962

This airplane is difficult to trim since it's oscillatory in pitch. Attitude control is poor. Normal acceleration is not a problem.

I picked a low gear ratio to give me a little damping of the oscillations in pitch which the pilot would tend to cause if the gear ratio had been higher. Even small transients in the airplane would tend to pitch up and down.

Although this airplane is oscillatory in pitch, and it changes attitude, it does not necessarily change flight path. It just oscillates about a point and the flight path may remain constant. In straight and level flight I can hold altitude fairly well; in turns it is a little more difficult because I'm holding force.

I'm relaxed a little bit and the airplane will oscillate about a given rate of descent or ascent. So this oscillation in pitch is most apparent when you're maneuvering. If you, in smooth air, will level the airplane up straight and level, you can hold it damped out for periods of time.

I tried 60° bank angles and was able to do them for a short period of time, but this pitch oscillation would develop and I would either end up going down at quite a steep angle, or going up at quite a steep angle. And I had some difficulty holding my airspeed, so I would recommend that this airplane be limited to a bank angle of less than 60° and I would guess that 30° would be adequate. In this way you could make turns holding altitude reasonably well.

Maintaining airspeed is a little bit of a problem, but my throttle corrections have to be made quite frequently.

So this airplane, which I thought was very bad at first, by selecting a fairly low stick ratio of 30 and then by flying through very small angles of pitch and roll, I was able to control it reasonably well.

It's an unsatisfactory airplane, however, in that you have a constant pitching motion which does not change the flight path of the airplane necessarily, but it's there and when you place the airplane in a climb or descent you can never stabilize on a given value. You're oscillating about some value or in an envelope on either side of the given value.

It's not a dangerous airplane. There is no danger for instance with this airplane in exceeding your g limits. It's just that the pilot does not have precise control.

Special piloting techniques on this airplane? I think to give yourself the best control possible is to maneuver very slowly and carefully; hold your angles of change from level flight to a very small ratio.

Instruments are satisfactory.

I'm going to rate this a 6. I certainly wouldn't rate it any better. I was considering rating it a 7 at one time, and then a 6.5, but after flying the maneuver I feel that it's a very unsatisfactory airplane and bad, which the rating calls for. But once you stabilize in level flight you can hold it there for quite a long period of time if you ignore the small pitching motion which doesn't change your flight path. It's only the attitude of the airplane that is pitching on its axis. So the rating is 6.

PILOT A
CONFIGURATION 35, ROUGH AIR, 29 MARCH 1962

This rough air gave very, very small indications of accelerometer on horizon indicator. The pilot required assurance when he trimmed up. I was able to minimize altitude, attitude and airspeed to practically plus or minus zero during two minutes of recording. I could fly this rough air configuration indefinitely. It indicates that I would be under no acceleration load at all, maybe .1 g easily. The horizon was disturbed only small amounts. I'm able to hold my values of airspeed. After the recording was turned off, I made turns and actually it apoeared to be that I was able to stabilize better in turns during climbs and descents in rough air than I had been able to do in smooth air. I don't quite accept this just from my experience in airplanes. No matter what the airplane did in flight in smooth air, generally my experience showed that in rough air, pitch is worse. But this configuration appears to handle better in rough air than it does in smooth air. I'm going to rate it the same as in the smooth air configuration, a 6, with the understanding or explanation that for some reason it appears to be doing a more precise job of flying in maneuvers and straight and level flight than it did in smooth air. I don't think this is true in actual practice. Generally, no matter what the stability or handling qualities of an aircraft, rough air tends to be a more difficult flight regime than smooth air.

PILOT A
CONFIGURATION 38, SMOOTH AIR, 30 MARCH 1962

This airplane is a little difficult to trim. It's attitude control is a little oscillatory in pitch.

I think perhaps it needs a little more damping. The pilot sort of acts as the damper in this loop.

Normal acceleration control is a little problem. It has to be watched, but with reasonable care there should be no reason for exceeding your structural limits.

I picked a relatively low gear ratio of 15. It does not give me full g-limiting protection,

but it gives me some g-limiting protection. It is a lower gear ratio than I would like for this configuration if I had protection from g-limiting. I think I would have picked something a little higher, because this gear ratio gives me fairly high stick forces, especially in steep turns.

I can hold altitude within certain limits in turns. In straight and level flight, I can hold it fairly well. When I try to set up a rate of descent or climb, I have to fly quite carefully in order to maintain a given rate of descent or climb.

Up to 60° of bank angle is usable. The stick forces are a little high because of the gear ratio I picked.

You have to program your throttle to some extent, but it is not a real problem. Airspeed does not bleed off rapidly, or increase rapidly.

No special piloting technique is required, but the pilot has to fly this airplane if he wants to hold precise altitude for instance. He has to fly it, because it will not maintain itself.

If you change from level flight to a descent, for instance, it takes quite a while for the pilot to damp out his pitching oscillations and stabilize on a given rate of descent. As I stated before, it is a little oscillatory in pitch.

It is also with the low gear ratio - it is a tiny bit sluggish to respond sometimes from, for instance, pitch-down to pitch-up.

There is some overcontrol that goes along with this configuration. The pilot overshoots when he is either climbing or descending and then wants to come back to level flight. There is an overshoot and he comes back to level flight attitude.

I am using normal instruments and they are acceptable.

This is a moderate configuration; I am going to rate it 5.

PILOT A
CONFIGURATION 38, ROUGH AIR, 30 MARCH 1962

Pilot was able to minimize his attitude, altitude and speed changes and was able to hold straight and level flight during the two-minute record run. The effect of rough air is not noticeable.

He is getting small excursions on the accelerometer about ±.2 g. I think the effect of random noise or rough air in this configuration is what you would expect in an airplane when you encounter light to moderate turbulence. There are no real adverse effects.

The pilot has about the same ability to fly, except he would be exposed to small accelerations. The instruments – the attitude gyro and his rate of climb – would be dithering back and forth a little bit, and he would have to perhaps work a little bit harder flying the airplane than he would with smooth air.

I think the effect of rough air on this configuration is closer to what happens in a normal airplane than anything I have seen, at least recently, during this evaluation.

To indicate that it is a little bit worse, I am going to rate it a 5.5 on the rough air. I could fly it indefinitely on this configuration in rough air. I could maneuver and perform climbs, descents and turns. So 5.5 is representative of this airplane in rough air I think.

PILOT A
CONFIGURATION 61, SMOOTH AIR, 11 APRIL 1962

This airplane I think is – yes – is a low 1_{α} configuration, because there seems to be poor resolution between the flight path, the flight attitude.

The airplane is fairly reasonable to handle if small pitch angles and bank angles are applied. If pitch angles are applied, I can hold my attitude reasonably well.

Normal acceleration was a problem with the high gear ratio that the airplane was given to me.

I lowered the gear ratio and finally picked one of 50 at which acceleration I have g-limiting protection and I have reasonable handling qualities, but the gear ratio could be improved on. If I had to pick it for handling qualities only, I would want less control stick motion than I have now. But I picked what I did to obtain g-limiting, and the control stick motion I now have is completely flyable, but it's not satisfactory.

I can hold altitude satisfactorily. In straight and level flight and in 30° turns, I can do a reasonable job of holding altitude. In 60° bank angle turns, I'm not doing even a fair job of flying the airplane. I'm doing a poor job. I would recommend that 60° bank angle turns not be used in this airplane.

However, at 30° of bank angle your radius of turn would be tremendously large because your rate of turn is so small. So this airplane needs better turning capabilities because it's a high performance airplane. The fact that the handling qualities are, and the stability is poor in 60° turns indicates that this airplane is not satisfactory.

The biggest problem with this airplane is that the flight path does not immediately coincide on align itself to the attitude of the airplane. So when the pilot applies a control input, it changes the attitude of the airplane. He then has to wait while the airplane flight path corresponds to the attitude, and for this reason I say it is a low L_α airplane. For instance, in pitching I pitch over to a fairly steep descent, and then to change my flight path would require quite a long time and considerable control input. The attitude of the airplane would change and then gradually as the attitude changed, the aircraft flight path would slowly start to correspond to my attitude.

Airspeed changes are quite large here. If you use steep bank angles in the turn, or if you use steep pitching angles, the pilot has to be very careful to watch his airspeed and program his throttle accordingly.

This aircraft could very definitely use a flight path indicator of some kind. When you are in a descent or a climb and your rate of climb so indicates and you want to change the flight path, you change the attitude of the airplane and then you sit and wait and suddenly the rate of climb needle comes off the peg and it pulls in the other direction. From there you change the attitude a little bit again, and then you'll finally catch the rate of climb needle. You reduce this angle until you get it back to level flight. So a flight path instrument would be a very definite asset here.

The throttle programming on this type of configuration might be a very great help to the pilot because so many changes in power settings are required and they are frequent. They are not large, but they are frequent.

This configuration is unsatisfactory in some respects, and I think it is kind of acceptable in others. For one thing, since the airplane does not have the capability of really steep turns because the handling qualities are so poor, the turn radius of this airplane is very, very large. You have to make turns at varied degrees of bank angle where you can handle the airplane. This is undesirable because it takes so much area to turn the airplane. Pitching angles have to be held to a minimum also, or you get into this problem of flight path versus attitude and the fact that they don't correspond, so it's a kind of an unsatisfactory, unacceptable airplane. I have been wavering from 6 to 7 and bank again. I can't really make up my mind, so I'm going to make it a 6.5 airplane. So the rating for configuration 61 in smooth air is 6.5.

PILOT A
CONFIGURATION 61, ROUGH AIR, 11 APRIL 1962

This I think is kind of ridiculous. I just flew this airplane which is not very acceptable or satisfactory; it's unsatisfactory, unacceptable. Rough air had absolutely no effect whatsoever on this configuration. The accelerometer may have moved, but it was such a minute quantity that I couldn't see it. I saw about two small inputs in my attitude horizon and rough air, if anything, improved this configuration. I don't think this is right. The configuration I flew in smooth air is worse than the one I flew in rough air, and I don't think this would be true of any airplane. I think there may be methods of handling rough air to configurations maybe open to question. I was pretty confident when I saw this configuration that I just rated on smooth air that when I got it in rough air it would be quite a bit worse. For when I put small inputs in, for instance and let go of the stick, the accelerometer would go in the opposite direction before the thing would damp out. I'm going to rate this 6.5 for rough air, but I think it is kind of ridiculous that we have a random noise in there and the pilot can't see any random noise at all. I don't think this is true of any kind of vehicle or

aircraft or configuration. In my opinion we should look at how we are simulating this random noise for some configurations, because there's no random noise here. It's not a tremendously good configuration either. It's one where the flight path and the aircraft attitude may not always coincide. I think it is a low L_α configuration, but I don't quite agree with just what I saw and I don't quite understand it because the airplane looked to me like in rough air it should handle differently from what I just saw. In any event, 6.5 for rough air.

PILOT A
CONFIGURATION 62, SMOOTH AIR, 11 APRIL 1962

This appears to be a configuration I think with high L_α where pitch attitude doesn't change very much but your responses are very high. Flight path seems to change quite rapidly. It is oscillatory; difficult for me to stabilize.

I had to pick a gear ratio of 10 in order to give myself some g-limiting protection.

This airplane is difficult to trim. The trim knob is extremely sensitive. In fact, you just squeeze it and you get some trim change.

Attitude control is very oscillatory.

As I stated before, normal acceleration control is a problem, a great problem, until I reduced my gear ratio to 10 and this gives me about 85% g-limiting. But it also gives me very poor handling qualities from the standpoint of my side controller motions to control input motions which are quite large to obtain an attitude change in the airplane. It's not satisfacory as far as handling qualities are concerned, but I felt that I had to bring my gear ratio down to this point to get g-limiting protection, at least as much as I did get at this point. It was a compromise as it usually is.

I can hold altitude in straight and level flight and to some extent in turns, providing I do not let my pitch angles become too steep in either direction.

This airplane tends to be very oscillatory in pitch, and if you get a pitching motion started up for instance, you fly control to stop it and always you overcontrol when your pitching motion changes from up to down, and it changes very rapidly. It starts to pitch down and you're now in a pitch-down. You apply control to correct this and you overshoot in the other direction. You gradually, through this process, narrow it down and bring it back to level flight. If the pilot is not careful you get very high accelerations along with inputs and so you have poor stick ratio from the standpoint that the motion inputs have to be very large. It's an oscillatory type of thing, your overcontrolling factor that the pilot has difficulty overcoming.

So it appears that the best way to fly this airplane is to keep the pitch angles to very small values. If you can hold your pitch angles to very small values, you can use 60° bank angle turns in this airplane. However, if the pitch is up to hold rate of climb scale in order to get back to level flight here, you're going to overcontrol.

It's an airplane that requires a lot of pilot attention and a precision job of flying is impossible.

Maintaining airspeed is no problem at all on this airplane, airspeed hardly ever moves. The pilot can handle that portion of the control system very easily.

Special piloting technique - as I explained - keep your pitch angles to absolute minimum and watch your accelerations while maneuvering. I think again a flight path instrument would be useful here, very definitely. It would be a g-limiting device so that you could improve your gear ratio on your stick.

This is a fairly poor configuration. I'm going to rate it 8.

PILOT A
CONFIGURATION 62, ROUGH AIR, 11 APRIL 1962

Rough air had a very pronounced effect on this configuration. Excursions on my accelerometer were ±2 g.

The pilot's ability to hold attitude and altitude and airspeed during the recording run was not

good. One of the problems was that when the airplane was deviating in pitch, the pilot had to be careful about the control input that he used because his control input and a gust both coupled in the same direction, the combination of the two might be high enough to exceed the load factor of the airplane. I went off the system because I did exceed my load factor. The handling qualities of this airplane in the rough air condition are poor. Also, the pilot is also constantly subjected to high load forces which are indicated by the excursions of the accelerometer and I think the combination of the two would make this a dangerous airplane, extremely difficult to fly. I doubt if it could be flown for half an hour. I would say that this would be the absolute maximum time. Sooner or later, flying this airplane with the combination of poor handling qualities and the high accelerations, pilots would exceed his load factor and he probably would suffer some kind of structural failure. So I want to point out that it is not completely unflyable, but it is right on the edge. I'm going to rate it 9.5 for the rough air portion. The flying qualtities, the accelerations are high, and if either one were just a little bit worse, it would be completely unflyable. But it is flyable for a period of time, but if the pilot makes one little error or mistake or rapid control inputs, that's all. So it's a configuration that is right on the verge of a 10, but I'm rating it a 9.5.

PILOT A
CONFIGURATION 65, SMOOTH AIR, 16 APRIL 1962

This airplane has fairly good trim qualities and it has a groove. I'm able to hold it straight and level quite well.

Attitude control is fair. Once you get it off the trim speed, it's oscillatory in pitch a little bit.

Normal acceleration control was a very definite problem but I kept reducing my stick ratio from the hand-off ratio which was quite high. I reduced it down to 30 which I picked as my stick ratio and this gives me considerable g-limiting protection. It is not complete, but it is fairly safe g-limiting protection. It also gives me some damping relative to my stick inputs to the elevator because this originally was a very abruptly responding configuration. The stick input affected an immediate response in the airplane and it was too abrupt. This goes along with sudden high g forces. In order to give myself something reasonable in this respect, I had to pick this gear ratio. I still have fairly good handling qualities.

I can hold altitude straight and level very nicely. I can hold it in 30° banked turns very nicely. At a 60° banked turn, my stick forces are a little bit high and the airplane is a little oscillatory in pitch. The airplane is a highly responsive fighter type anyway, and a small squeeze on the controls will affect an attitude change. In 60° bank angle turns, it's a little difficult to completely stabilize. In 30° bank angle turns, I can stabilize rates of descent and climb as well as level flight. I would say that it's good in 30° turns, but 60° bank angles or turns are usable, but it is a little more difficult to stabilize.

Maintaining airspeed is a slight problem here. The airspeed needs at least normal attention. As the pilot surveys the instrument panel, he must include the airspeed instrument in his 1 - 2 - 3 survey of attitude correction, altitude, etc. The airspeed has to be reviewed constantly.

Special piloting technique? This is a highly responsive fighter aircraft and when maneuvering, the pilot should be aware of the fact that he could overstress the airplane. I have given myself a stick ratio that gives me some protection but it's not complete.

The instruments are adequate for this configuration. It's a pretty normal airplane.

In summation, this was a highly responsive fighter airplane. It still is a little oscillatory in pitch which presents itself when the pilot is performing 60° bank angle turns with the stick forces being a little heavy. Any small motion will produce a little pitch oscillation. The trim of the airplane in straight and level flight is good. 30° bank angle turns can be performed very well as well as rates of descent. I like the feel of the controls. I would say that this airplane needs g-limiting protection in which case the pilot could perhaps change his gear ratio so that 60° bank angle turns would be more acceptable. Also, perhaps a little more damping in pitch would be desirable here. It's a fairly good flyable airplane. I've got to rate it a 3. I do have my suspicions that it may not be so good in rough air. I can groove this airplane and it sure handles well in level flight.

I want to make some separate comments relative to the rate of climb instrument which has

been installed since my previous flight. The new rate of climb instrument which has a scale from 0 to 10,000 feet, either climb or descent, is nice. The increments on the scale between each thousand feet are so small that it can only be used with another reference instrument such as we have here in this airplane. We have the rate of climb instrument that we've been using which has a scale from 10 to 3,500 feet. Neither one of these instruments alone is acceptable. This I think is regrettable. I have ideas but they're too lengthy to put on this wire with reference to an instrument that would be acceptable to do both jobs. It would have increments between each thousand feet large enough so that you could read it easily. I will say that with the new instrument installation, from 0 to 10,000 feet up or down, it is a definite help when you are doing steep angle climbs or descent. The instrument that now has been installed in the airplane makes it possible to refer to instrument No. 2 and read your approximate rate of descent and climb. My point is that I have ideas that I'm sure we could use or incorporate all of these features into one instrument which is something that is desirable because the pilot has enough instruments to watch without adding additional ones. The installation of the new instrument is of definite value, but on future programs I would like to see all the information that is recorded on these instruments incorporated into one. I have ideas that would make this a relatively simple task.

PILOT A
CONFIGURATION 65, ROUGH AIR, 16 APRIL 1962

I was certainly wrong about the effect of rough air on this configuration. I had anticipated that it would be quite a rough ride but the rough air or random noise that was fed into the simulator showed very small excursions on the accelerometer. I think that indications were that this airplane would handle very much like what I'd call a normal airplane under rough air conditions. By saying normal airplane, I mean the airplanes that are flying today, the B-26 for example. I saw small excursions on the accelerometer, small attitude changes in pitch and roll. I could fly the airplane indefinitely. I didn't do a really good job of holding altitude, attitude, and airspeed. I let it get off at the beginning. I could do a fair to good job. The effects of rough air have not been bad at all here. They've had a very normal effect on the airplane and an acceptable effect. I'm rating it exactly the same - 3 for rough air. One comment I'd like to make applies to both rough and smooth air. Due to this low stick ratio that I had to pick, when control applications aren't necessary, it requires quite a bit of motion of the side stick controller to effect the attitude change in the airplane. I would like to see some of this motion cut down to make a more pressure type of control. Of course, the way to do this is to change the gear ratio. Increase it and have a g-limiting device on the airplane. That's one of the reasons why this airplane was not given a better rating.

PILOT A
CONFIGURATION 66, SMOOTH AIR, 16 APRIL 1962

This airplane has fair trim qualities. Attitude control is bad to poor - very bad.

Normal acceleration control was not a particular problem.

I started out with a considerably higher gear ratio than I finally decided on. I decided on a gear ratio of 30.

It appears to me that this has to be low L_α because I get rapid attitude changes, but it takes a long time for the airplane to change flight path.

I can hold altitude straight and level. I can hold it reasonably well in 30° bank angle turns. In 60° bank angles, I have no luck at all. I would say that 60° bank angles are usable momentarily, but generally this airplane is one in which you would restrict yourself to 30° bank angle turns. You would also restrict your pitch angle to something that was quite small. You would make your rates of descent at small angles.

Maintaining airspeed is definitely a problem. It's an airplane that has very poor handling qualities.

The feel of the control stick is not positive. You feel that you have partial control of the airplane. It's sluggish to respond. You need a lot of control motion. You don't feel that the coupling between the pilot's stick and the airplane response is linear at all. It's a difficult airplane to fly. It doesn't have position control, as a matter of fact.

It's oscillatory in pitch even though you are able to finally bring the airplane to the pitch

attitude that you desire. You can't pin it down even then. This is not a good airplane, yet it's not really a dangerous airplane.

As far as piloting techniques are concerned, I would hold my pitch angles to small values and I would restrict myself to 30° bank angles.

This is an airplane that could use a flight path instrument to advantage. There's no question that the rate of climb going from 0 to 10,000 feet is of value in this configuration. I use that instrument.

This configuration takes a considerable amount of the pilot's attention to fly it. This is mostly because when he sees that he is deviating in one direction and he makes a control correction, he has to continue to watch rate of climb, airspeed, and attitude to find out when his control input effect is going to take place. Then when it does take place, he has to decide in advance when to put in the opposite control input to pin it down at a given rate of climb or back at level flight because of the lag in the system.

Airspeed is a definite problem here. We could use throttle programming on this configuration. This might help the pilot to some extent because then he would know that his airspeed at least was being programmed for him and all he would have to do is maneuver the airplane.

It's a poor configuration, not dangerous, but poor. I'm going to rate it a 7.

PILOT A
CONFIGURATION 66, ROUGH AIR, 16 APRIL 1962

Rough air had absolutely no effect on this configuration. A further explanation - there was no evidence in the cockpit that we were going through rough air except a very small trembling effect in the attitude gyro occasionally. This is probably a good thing because this is a pretty bad configuration as far as handling qualities are concerned. If you introduce some bad qualities as the effect of rough air, it probably would have been a 10. As it is, I can't make it any worse for rough air than for smooth. The rating will continue to be 7. I want to say again that the handling qualities of this configuration are extremely poor. At 1800 knots, the pilot should have something fairly good as far as longitudinal control and stability are concerned and he does not have it here. At 10,000 feet rate of descent at 1800 knots, I haven't figured this out, but he's going down hill at a pretty good clip. We can't have this sort of thing. You have to have an airplane where you have good positive control. You can't be pitching ±10,000 feet increments here. So rating of 7 for configuration 66.

Rough air had no effect on it. I can fly it indefinitely in straight and level flight. Maneuvering qualities of the configuration are as poor as ever. The whole secret of this configuration is to keep your pitch and bank angles to small values. Don't deviate very much from straight and level flight. An airplane that travels at 1800 miles an hour - this is a little ridiculous because it would take the whole state of New York just to turn her at a 360° turn at 10 or 15° bank angles.

PILOT A
CONFIGURATION 67, SMOOTH AIR, 16 APRIL 1962

This airplane is a little difficult to trim. It's a highly responeive airplane and I would guess that it's a high L_α configuration. Attitude control is not too satisfactory. It is an airplane that is highly responsive to pilot inputs. Large rates of climb occur with no change in airspeed for very small attitude changes. The attitude horizon shows hardly any change and yet we could be ascending or descending 5000 ft/min. For this type of configuration, we probably need a better attitude indicator in pitch. I'm using my rate of climb as an addition to my attitude indicator. I'll go into that later.

Normal acceleration control is very definitely a problem.

I picked a gear ratio of 70 on the low scale - 7 or 8 would have been acceptable. With this gear ratio, I still have a fairly highly responsive airplane. I have almost full g-limiting but no complete. I have to exercise caution when maneuvering because I could still exceed the load limit factor of this airplane. I picked the gear ratio to give me two things - g-limiting and also a factor to damp out some of the highly responsive attitude changes to control inputs. Because this airplane is so highly responsive, its pressure input on the

pilot's control will change the attitude. Consequently, it has to be held very carefully to hold straight and level flight and to hold altitude in turns.

Up to 60° of bank angle are usable. Stick forces, however, are quite high. This airplane should have g-limiting protection very definitely. Then the pilot should be allowed to have lighter stick forces.

Maintaining airspeed is no problem. Airplane stays grooved at 1800 mph. I can change the throttle until I started making large rates of descents and climbs and I held them for some time, then the airspeed would change. Otherwise, no throttle programming is necessary.

Angle of attack didn't move.

The special piloting technique here is to be definitely cautious of your control inputs during maneuvering because you can exceed your load factor.

To use rate of climb with ±0 to 10,000 range is of great help with this configuration because the airplane is highly responsive. The rate of climb that was installed in the simulator pegs either up or down. With the new rate of climb, you can see what's your rate of climb or descent, whether it's increasing or decreasing; and it definitely helps to stabilize the attitude of this airplane. It's an instrument that the pilot uses. For the information he gets there, he can bring back to level flight. This is definitely helping me in this configuration.

I would recommend for an instrument here that we need a better attitude presentation in pitch. The present attitude gyro does not displace far enough to give the pilot enough information. With it displaced only a small amount, you get very large rates of climb or descent.

In summation, I think that this is a high L_{α} configuration. It has highly responsive flight characteristics to controller inputs.

G limiting was a problem. It should have a g-limiter on it so that the pilot could pick a better gear ratio on his control stick and get lighter forces, especially for turns. Because this airplane is so highly responsive, it tends to be oscillatory unless it's handled with a very fine touch. The rate of response, actually, is more than the pilot needs. This should be cut down. The g-limiting should be damped out in some manner so the pilot's control inputs would be smoother, so that he could come back to level flight more smoothly. The airspeed did not change and this I liked very much. Apparently there's not much drag effect on this airplane for change of flight angles. The angle of attack changes very little, if any. I repeat that I used the new rate of climb instrument on this configuration. If it had not been for the new rate of climb, this would probably have been given a higher rating because I would always be in a pitching motion. My rate of climb, the old one that was installed in the simulator, would always be in transient, either pull-up or pull-down and it would be difficult to stabilize it.

I like a highly responsive airplane, but this one is just a little bit more than I can handle. I'm going to rate it a 5.

PILOT A
CONFIGURATION 67, ROUGH AIR, 16 APRIL 1962

Rough air had an adverse effect on this configuration. Besides seeing excursions on my accelerometer of ±.8 g, the handling qualities and stability of this configuration has been affected by rough air. As I stated, for smooth air, it was highly responsive. In rough air now, it's really difficult to pin down level flight. In smooth air, you could do it with care, but in rough air, it's a little difficult. On this configuration, the pilot would be very busy holding his flight path. When subjected to ±.6 to .8 g, at fairly high rates of change from one to another, I don't think that it would be a very pleasant airplane. As I stated for smooth air, you have this highly responsive control. Just a squeeze on the input gets a response from the airplane. The pilot's hand would be subjected to those accelerations that I've seen. He would inadvertently be putting inputs into the airplane. It's probably a system where you'd have to trim it up and fly hands-off as much as possible. It could be quite bad. It probably could be a lot worse than I'm going to rate it. I don't think that I care to fly it for more than a half an hour. I think that my ability to fly straight and level flight path with this would be poor. I don't think that you should have an airplane that is as highly responsive as this one flown under rough air conditions where you're being subjected to

±.8 g. The trim knob is very effective for this configuration. During smooth air, I used the trim knob to help my airplane. In rough air, I trim up for straight and level flight and I wouldn't deviate far from straight and level flight. I would try to make very shallow turns. I would try to keep my pitch angles very low. I would certainly endeavor to keep my control inputs to the minimum. By doing this, we could probably fly this airplane for half an hour at a time, but it's an airplane that could get dangerous. If the pilot should tighten up on the controls while subjected to these accelerations, I'm afraid that you'd get some pretty high inputs and you'd get some good large pitching motions. I'm going to rate it 8 for rough air.

PILOT A
CONFIGURATION 69, SMOOTH AIR, 17 APRIL 1962

I think this configuration has a low L_α. The airplane can be trimmed up for straight and level flight.

Attitude control, of course, is poor, because the resolution between attitude presentation to the pilot and flight path are poor.

Normal acceleration control is not a problem.

I picked a gear ratio of 175. Gear ratio with a configuration like this is something where there could be a lot of leeway, I think. I could probably have picked 150 too, without too much difference. However, the reason that I changed from 200 to 175 was that in straight and level flight with 200, I found myself jiggling and making small attitude changes on my horizon. This was at a gear ratio of 200. At 175, I had a little more damping and I didn't tend to jiggle my attitude horizon. So my gear ratio is 175 and this gives me plenty of g-limiting protection - there is no problem there. My handling qualities are reasonable with a low L_α configuration.

Sluggish response of the airplane in response to pilot control inputs is not acceptable because the two actions do not coordinate each other. The resolution is poor. Pilot applies an attitude to the airplane and he has to sit and wait while the flight path of the airplane catches up with the attitude. This I don't like.

You can use bank angles in turns up to 30°, but it is difficult to stabilize. You are either pitching up or down. I find it very difficult to stabilize in level flight at 60° bank angles – I would recommend something less.

And in a low L_α airplane anyway, I would recommend not applying control motions that will bring you in these very steep pitch angles – keep your pitch angle to a minimum, keep your turn and bank angles to a minimum.

Maintaining airspeed is somewhat of a problem with this type of configuration. The airspeed tends to bleed off quite rapidly when you are maneuvering. It is nearly always a condition of bleeding off. However, sometimes it will build up, but generally it is a bleed-off condition. When you enter a turn for instance, the airspeed will bleed off very definitely. You must stand ready to control it hands-off.

This low L_α configuration – the piloting technique required here I think is one of: do not get into situations where steep bank angles or steep pitch angles are required, keeping these angles down to quite small values and in that way you will be able to keep your attitude and your flight path more closely aligned or parallel, or the resolution between them will be more nearly normal because this airplane needs a flight path indicator and you get very large indications of pitch angle on your horizon. You have to sit and wait until your flight path catches up with this pitch angle. In the meantime, you have to program your throttle, watch your rate of climb come up or down, whichever the case may be, and this is not desirable.

Incidentally, the 10,000 feet per minute rate of climb is a very desirable instrument for this configuration and an airplane with this capability – 1800 mph – should definitely have rate of climb with even greater capability than 10,000 feet. The instruments between each 1000 feet should be greater, especially the 0 to 5000 feet level on either side. I think this could be designed into a single instrument. The problem of having two rate of climbs is not too satisfactory, but generally the pilot has too many instruments to watch anyway, but I wanted to make the point that a 10,000 feet scale rate of climb would be a very definite help in this configuration. The trim knob incidentally has practically no effect when it is

rolled full nose-down to full nose-up in this configuration. This was a sluggish low L_α configuration, safe to fly, but not desirable. I don't like it. It's not dangerous at all. I'm rating it a 6.

PILOT A
CONFIGURATION 69, ROUGH AIR, 17 APRIL 1962

Rough air had no effect at all on this configuration. There were no excursions on the accelerometer. Perhaps just a little bit of indication on the rate of climb. The pilot was able to hold altitude, attitude and airspeed perfectly during the two-minute record run.

This is a low L_α configuration and the secret of this configuration to fly it is do not deviate from the straight and level flight path any further than absolutely necessary. When you start maneuvering this airplane, that is when you get problems, so maneuver it carefully and at as small as possible angles and you can fly it indefinitely. You can fly this airplane all day in rough air, no problems. I am going to rate it the same as for smooth air - 6. The problem with the configuration in the handling qualities – dynamics of this type configuration in the maneuvering – very poor maneuverability. It needs a flight path instrument or indicator instrument because of poor resolution between attitude and flight path.

PILOT B
CONFIGURATION 9, SMOOTH AIR,

I would say this is not a very good configuration. We have here quite a responsive airplane in pitch attitude, but not very responsive in lift generation.

The gear ratio I started with was at 400, I finally ended up at 200. The reason I chose the gear ratio as low as I did was because with the higher gear ratio I was overcontrolling quite a bit. I had difficulty pinning down the pitch attitude and the abrupt responses in pitch, I'm sure, would be very unsatisfactory to anyone riding in this aircraft. On the other hand, the gear ratio I finally chose was too low because the controller deflections required were quite high and in a turn, the pilot's wrist gets tired quite quickly. Also, there was a feeling that the pilot may not have sufficient elevator control for large amplitude maneuvers. Again, like most of the other configurations, the gear ratio is strictly a compromise. With a gear ratio of 200, I was able to do a halfway decent job of flight path control.

However, it does require much pilot concentration, especially when performing turns. This airplane would definitely be restricted to bank angles no larger than 30°. The power required to maintain a 45° banked turn is quite high, but that isn't the real prohlem. The real problem is that once the rate of descent gets beyond approximately 500 ft/min, and if the airspeed starts dropping off as the pilot pulls back on the stick to stop the rate of sink, the power required for recovery is tremendous (just about full throttle). Just now as I was talking, I let the airspeed get quite low and rate of descent quite high and I'm sure I would have had much difficulty in recovering. We reset the computer so I didn't try to recover, but I'm not really sure that I could have recovered. I probably could have, but with a very large loss in altitude.

So, the things that are important in this configuration are: limitations in rate of sink and bank angles, limitation due to gear ratio, and the abruptness of the pitch response coupled with difficulty in maintaining the desired pitch attitude. I didn't actually have much trouble maintaining a stabilized pitch attitude, but I did have trouble in making small corrections to the pitch attitude.

I might comment on one more thing. The frequency response in pitch – short period oscillation – the period is about 2 seconds, maybe a little less and the damping appeared to be light, less than 30% or at least in that order of magnitude.

I think I would have to rate this configuration unacceptable. I'm debating between a 6 and a 7. I guess I can do a halfway decent job of flight path control, but I can get into trouble with this configuration, especially if I'm not careful when performing turns. So I think I'll rate this a 6.5. I hate to split the difference, but I don't really think that it takes the major portion of the pilot's attention. Well, I think I'll change my mind and rate this a 7 because I guess I do have to spend more than 50% of the time monitoring the airplane's performance. The rating is a 7.

PILOT B
CONFIGURATION 9, ROUGH AIR

I don't see anything that would change my mind about this configuration. The characteristics are the same as far as turns and so forth are concerned. The same amount of effort – a little more annoying perhaps, but not bad. So I think I will go along with a rating of 7. As a matter of fact, the airplane's lift response to the random inputs is practically nil, so the rider (as far as g was concerned) actually was not bad. There's quite a bit of pitching oscillation however, which I think would be quite annoying. Perhaps it would be very uncomfortable if you were sitting at either end of the aircraft, i.e., if distant from the cg, the angular accelerations might be very uncomfortable. I would say that when you get a situation like this you have a tendency to say, "Well, maybe this is one of the good points about this airplane – it can go through turbulence reasonably well". So you might even have a tendency to up-rate it from what you would in smooth air. However, I don't think I should do this. I shouldn't give the airplane a better rating just because it reacts well in turbulence, since it still has the poor characteristics in smooth air and if it has these same characteristics in turbulence, I don't think that the configuration rating should be changed. The rating in smooth air is based strictly on controllability of the flight path and the effort required by the pilot to fly the airplane and obviously these factors are not better in turbulence. Although it looks pretty good in straight and level (in turbulence), this shouldn't be a reason for upgrading it. So I'll just have to rate it exactly the same in rough air as I would in smooth air. It'll be a 7. One other thing that has been bothering me somewhat is that I downgrade some of these configurations because maneuvers are limited with respect

to bank angles. This of course is a limitation, but the seriousness of this limitation would depend entirely on the mission or function for which the aircraft is to be used. If this were a long-range transport (or something similar), where required maneuvering is at a minimum, a 30° bank angle limitation is not very severe and not very serious. So I may, in a sense, be penalizing the airplane just because I can't obtain or control large bank angles. However, I do feel that pilots being what they are and flying being what it is, there are times when pilots will be distracted by cockpit duties (or what have you). Under these circumstances, you can get into a situation that I think could be catastrophic. So this, I think, is the real reason behind my rating when I say there is a limitation on bank angles. I'm not sure that this is precisely right, but this is an indication of how I'm thinking in arriving at my rating.

PILOT B
CONFIGURATION 10, SMOOTH AIR, 15 MARCH 1962

This is a pretty good flying airplane all in all. There appears to be good frequency response short period on the order of .5 cps, and the damping looks like it's in the middle range, maybe around the 50% range. The L_α appears to be moderate.

I notice that I need a fairly large angle of attack in a 45° banked turn. The only objection I think I have to this limitation is the trouble I might get into in a turn exceeding 45° of bank. Unless power is applied soon enough, the rate of sink is likely to get away from the pilot. A very large amount of power would then be required to recover.

The gear ratio I chose is possibly a little on the low side. I would have liked it a little higher, but with higher gear ratios, I noticed I was inducing small pitch oscillations. So I'll stick with the one I have. I started at 150, went up to 300, finally ended at 175.

I think it is a pretty good flying airplane. The only limitation as I see it is that I would restrict the bank angle to a maximum of 45°. Turns with 60° of bank can be made but the pilot has to be quite careful. I don't really have much else to say.

I might comment that in the climbing turns and descents I was able to maintain reasonably good flight path control.

I think this airplane will have to be in the acceptable satisfactory range. I think it's fair, i.e., it has maneuvering limitations due to the high drag at high angles of attack, so I think I'll rate this a 3.

PILOT B
CONFIGURATION 10, ROUGH AIR, 15 MARCH 1962

I would say that no new characteristics showed up in this configuration, i.e., comparing it with the smooth air configuration. I think it was a pretty good ride. The acceleration amplitudes were quite small – less than .1. The airplane does respond in pitch quite snappily, but the amplitudes are reasonably small. The pilot can, if he wishes, track the pitch attitude fairly well. It would maybe help a little bit in the tracking if the gear ratio were a little higher, but all in all, I think this is a pretty good configuration. The rating of 3, I think, is quite good. I shouldn't change it at all because of the random inputs. There is a little more difficulty, of course, in flying precise rates of climb and rates of descent with the noise in, but outside of this, I think it's what you might expect in turbulence. So I think I'll just leave the rating at 3.

PILOT B
CONFIGURATION 40, SMOOTH AIR, 2 APRIL 1962

Well, the short period frequency is moderately high – appears to be in the order of magnitude of .5 cps, possibly a little higher. Damping in the middle range – somewhere around 50%. The L_α is moderate to low I would say. A 60° banked turn requires maybe 6 or 7° angle of attack.

The difficulty I had was in choosing the gear ratio as usual. The lighter forces at the higher gear ratios are preferable, but there is an overcontrol problem. So I think this is a combination of overcontrol tendency, high frequency, and the damping which is a little bit on the light side. I started out with a gear ratio of 300 and went up and down the scale and finally ended up at 150. The only real difficulty I have even with the gear ratio that I

chose, is precise control of the flight path. I have to work pretty hard to stabilize at any desired rate of climb, whether it be 0 or 1000 feet/minute climb or a 1000 feet/minute descent. However, I can do a halfway decent job with this gear ratio. At the higher gear ratios, I had much more difficulty and also at the lower gear ratio, I did a better job, but then the stick forces appeared to be somewhat high. So it is a compromise.

All of the difficulty isn't completely related to the frequency and damping. I think the L is partly at fault. Apparently there is a slight time lag in the response so that there is a tendency for the pilot to force the airplane response a little bit – not much, but it is there – and this gets to be a problem when making small corrections because an oscillation is induced. This is the type of oscillation that I referred to previously. Also, I think the friction level of the pitch control has something to do with the difficulty in making small corrections. It's not actually a very bad airplane.

I think it would be quite difficult to be smooth air it, but on the other hand, it is the type of airplane that allows the pilot to make a 60° banked turn – with some difficulty but without the risk of getting into dangerous situations.

Power manipluation is moderate, i.e., moderate power is required in steep turns.

I may be influenced a little bit by the fact that a 25 knot change in airspeed represents only approximately 1/16 inch deflection of the airspeed needle. Therefore, airspeed control may appear to be better than it is in actuality. I would say that without careful monitoring, the airspeed would wander around quite a bit – as much as 50 knots from the reference **700 knot airspeed.**

So it is an airplane that is acceptable. I think it is definitely unsatisfactory and the difficulty in obtaining or maintaining some desired flight path is substantial. So I think I would rate this somewhere around 5. I may be penalizing it a little bit, but I just don't like the fact that the ride quality is influenced adversely by the pilot's control inputs. So I am going to rate this acceptable, unsatisfactory, poor , a 5.

PILOT B
CONFIGURATION 40, ROUGH AIR, 2 APRIL 1962

After flying it with the random input – well, it was an uncomfortable ride, but only moderately so. I thought the ride was no worse than might be expected in moderate turbulence with a conventional aircraft. Acceleration responses were generally less than .2 g, usually ±.1 g with an occasional excursion as high as .2 to .3g. The pitching accelerations were quite low – the amplitude of the pitching oscillation was no more than a couple of degrees. The pilot had very little to do except for an occasional input, either nose-down or nose-up, to prevent a climb or descent. So from a ride quality point of view, this is not a bad airplane. I don't think I will downrate it. I rated it a 5 in smooth air, and I see no reason for changing it. So we will rate that a 5.

PILOT B
CONFIGURATION 48, SMOOTH AIR, 14 APRIL 1962

There was a big transient there when I turned it on. This is a fair flying airplane. The frequency of the short period is quite low, I imagine around 3 seconds. The damping is moderate to light – somewhere around 40 or 50% (maybe). The L_α is quite low. About a 10° angle of attack is required for a 60° banked turn.

I had quite a bit of trouble in choosing a gear ratio. It seems a little bit nonlinear as a matter of fact. It seems that for small corrections, I have a tendency to overcontrol — not so much in g as in pitch attitude. It doesn't seem as though I'm getting very large angle of attack changes for moderate bank turns. When I get up into the 60° banked turn, the angle of attack goes up quite a bit.

I think the major parameter that is causing me the most difficulty is the light damping and the fact that I require a reasonably high gear ratio to be able to control the airplane in steep turns.

The gear ratio is actually a little bit high with respect to ability to make small corrections in pitch. It's a little on the low side, I would say, for the steep turns, although not badly so. I started at a gear ratio of 50, went up to about 75, down to 25 and finally settled at 40.

It requires a pretty fair amount of pilot attention to be able to make precise pitch angle corrections, i.e., controlling the flight path angle. I think this is an acceptable airplane but I think that it's somewhat unsatisfactory.

Also, the fact that the L_α is quite low means that power must be manipulated fairly frequently while maneuvering. There's a little bit of potential danger in steep turns. The airspeed will drop off quite rapidly unless power is applied reasonably soon and in sufficient amount. It takes roughly 1/3 to 1/2 of the excess power available to maintain a level turn with a 60° bank.

This is particularly noticeable with respect to rate of sink, i.e., when rate of sink has built up and you're trying to recover while still in a turn, the power required then could be even more. There is somewhat of a feeling that you may run out of power before you actually get the airplane under control – assuming that you don't level off the wings.

I think I would probably restrict myself to approximately 45 to 50° bank angle although I think that you could handle a 60° bank angle. I think that there's more effort involved in a 60° bank than I wish to expend on this type of maneuver.

I think that this is an acceptable airplane, but I think that it is unsatisfactory. This would be poor I think – yes, this describes it. I'm going to rate this a 5.

PILOT B
CONFIGURATION 48, ROUGH AIR, 14 APRIL 1962

This would be a fine airplane to have in rough air (if the random input represents rough air). The airplane response is very slight and generally under .1 g. There is an occasional response of maybe .1 to .2, but not quite .2. A very nice ride. Based on the riding qualities, this airplane would undoubtedly be rated between a 1 and a 2 – that is, if it were rated strictly on its ability to ride smoothly with the random input present. I can't downgrade it, so we'll leave it at 5, which is based strictly on its handling qualities.

PILOT B
CONFIGURATION 54, SMOOTH AIR, 6 APRIL 1962

This is a configuration which is difficult to really pin down. The short period frequency is fairly high and the damping is also fairly high. I imagine the short period frequency is of the order of 1/2 cps and the damping is about 50 to 70% I imagine, I would say 50 to 60%.

The L_α appears to be moderately low. It is difficult actually to pin this L_α down. I'm not sure whether it is changing or whether it is characteristic of the airplane – but if you roll into a steep turn and maintain the rate of climb close to zero and also apply sufficient power to maintain the airspeed, then it appears that just a moderately high angle of attack is required to maintain a level turn, i.e., 4 to 5° angle of attack is sufficient. However, if the rate of sink gets to be quite high and the pilot attempts to stop or reduce the rate of sink to zero by pulling back on the stick, the angle of attack goes up appreciably – maybe 10 or 20° angle of attack – and yet there is apparently no response. I say no response because the rate of sink is high and the rate of climb indicator is usually pegged under these conditions – which means a rate of climb of 3000 to 4000 ft/min. Anyway, there's a large lag and there's a large amount of power required unless the bank angle is practically eliminated. If you try to maintain a steep turn (or fairly steep turn) say at 45°, it requires a lot of power and a very high angle of attack to obtain an up indication on the rate of climb. Now, to the pilot, this feels the same as when you are flying on the backside of the power curve. So apparently the drag is going up very rapidly with angle of attack and it requires this tremendous amount of power to overcome it. Anyway, you get the impression that, in a sense, the L_α is at times much lower than it actually is. The way I interpret what I see is that this is a moderately low L_α. In other words, about 4 to 5° angle of attack is required to maintain a level turn with a 60° bank.

I had a lot of trouble choosing a gear ratio. It's quite easy to overcontrol. The acceleration response is not too abrupt, but the pitch response is quite abrupt and this makes it quite difficult to fly a precise flight path. So the gear ratio was reduced. I think I started at 300, up to 400, down to 100 and I finally chose 250. This is a compromise. At the lower gear ratios the stick forces are much too high and also the stick motions are much too large. At 250 I find that the stick motions actually act as a g-limiting or g protection rather than the stick forces. However, the stick forces are quite heavy. The controller

motions are quite high and I think this would give some g protection and also reduce the tendency to overcontrol in pitch attitude.

So anyhow, I'm not particularly crazy about this set of handling qualities. I feel that this airplane should be restricted to approximately 45° bank in turns. The 60° bank turns can be made, but it requires a low of pilot effort and, I think, too much pilot effort. So that's it. I can only do a fair job of controlling the flight path with this set of handling qualities. I think that this is an unsatisfactory airplane and I think it is also a bad set of handling qualities with respect to flight path control. This, of course, is the basic criteria in rating all of these airplanes. In other words, the amount of effort required to fly a good flight path, or to control the flight path, is the criteria. So I don't think this is very good. I'm going to rate this a 6.

PILOT B
CONFIGURATION 54, ROUGH AIR, 6 APRIL 1962

This is a mighty fine airplane with the random input. For straight and level flight, the g response, for all practical purposes, was nil. The pitch response was a little bit annoying but very low amplitude. So with respect to ride quality, this airplane would probably be rated pretty close to 1. So we'll just rate this a 6 with the random input. Absolutely no difference between the random input configuration and the one in so-called smooth air. So that's it. For ride quality, rate it close to 1, but with my philosophy in rating configurations with the random inputs, it just means that the handling qualities predominate, and it will be a rating of 6.

PILOT B
CONFIGURATION 61, SMOOTH AIR, 10 APRIL 1962

This is the first configuration I've seen with the reference airspeed of 1800 knots, and that's a pretty bad one. I don't like it.

I've been fiddling around with this thing for some time. I can't make up my mind on a gear ratio. None of them suit me. The basic characteristics are: short period frequency is quite low, in the order of about 1/4 cps, the damping is moderate - I see 2 or 3 overshoots on the accelerometer but this may be misleading because it is pretty hard to see the small amplitude oscillations. However, I'd say the damping is in the 30 to 50% range.

The L_{α} appears to be extremely low. To obtain a 2 g turn requires approximately 12 to 13° angle of attack. That's a low of angle of attack.

When I first obtained the configuration I was given a gear ratio of 200 and I immediately got into a pilot-induced oscillation. This is a little peculiar. The acceleration response is quite low. However, the amplitude of the pitch response is quite high. There appears to be some discrepancy between the normal acceleration response and the pitch. If I were to just look at the accelerometer, I would say to myself - this is a pretty low frequency and this is true. This is also true when I observe an open-loop pulse maneuver. However, when I'm in the loop and trying to fly a flight path, all of my inputs result in overcontrol apparently and are reflected in the attitude indicator. Therefore, the over-all impression I get by watching the attitude indicator is that it's quite a snappy responding airplane in pitch. Also, the fact that I overcontrol almost seems to give the impression that the short period has a fairly moderate to high frequency, when in actuality it's low.

There's a distinct impression, as I said, that there is somewhat of a mismatch in characteristics between what I see in the pitch presentation and what I see on the accelerometer. I can't really explain it or why this impression should be accepted. I have apparently a powerful elevator. It gives me a low of available pitch moment, but the lift is apparently quite low. The slope of the lift curve is quite low, so the g response is low. I suspect that all of my troubles are certainly tied in with my inability to precisely position the pitch attitude and at the same time the fact that there's a fair amount of lag in g response and I don't notice the error in the pitch attitude until it's a little late. Therefore I overshoot and I get the impression that I have a closed-loop instability in pitch.

Now I have successfully made 60° banked turns with a gear ratio of 60, with 75, and with 50. However, this is another of those configurations where you have to beware of the rate of sink and then be right there with the power. In a 60° banked turn, if the rate of sink gets to be quite large, it requires full throttle to recover. Even then it's a long time before you actually stop the rate of sink and bring the rate of climb back to zero. I don't know.

There's not too much difficulty in trimming the airplane. I've been talking for quite sometime now and the airplane has stayed pretty much in trim. But, there are enough control problems here that the pilot has to pretty much concentrate full time on the instruments while he is making any small corrections or maneuvers. I think the primary trouble is that the low frequency and low L_{α} is causing me to over control in pitch and as a consequence I can't really pin down anything. I can't pin down rate of climb too easily and I have to go to a fairly low gear ratio so that the small corrections, which I must make continuously, are not magnified to the extent that I feel I'm losing the airplane. This is what happened with a gear ratio of 200. I'm going to have to rate this unacceptable.

I would also say that I would certainly want to restrict this airplane to a maximum of about 45° of bank. You can make 60° bank turns, but it takes a lot of effort and could be potentially dangerous. So 45° bank angles.

I think these are an unacceptable type of handling qualities and I think that I did a very bad job of flight path control. I look at this rating scale and I always run into a mental block; i. e., choosing a rating of 9 because it's dangerous. I don't really think this airplane is dangerous to any great extent or more dangerous than many others I have seen. However, I do think it's unacceptable and too much effort is required to do a good job of flight path control. In other words, I'm being pushed pretty much to my limit in order to do a good job. I would say that on the basis of flight path control and amount of effort involved in doing the job, that this might be a 9, but I hate to use 9 because of that word dangerous. This could be dangerous I suppose under particular circumstances, such as in a landing approach. The poor control that I have over the flight path could be dangerous at low levels. However, for cruise and small amplitude maneuvers and so forth, it would not be a very smooth ride, but I wouldn't say it's dangerous. Well, what a question. I'm going to rate it 8 1/2.

PILOT B
CONFIGURATION 61, ROUGH AIR, 10 APRIL 1962

Configuration 61 following the evaluation with the random input. With respect to ride qualities, I would rate this airplane a 1. There isn't any better rating than that. The normal acceleration response was just barely perceptible (if I looked real close). There was some slight pitch response, but practically speaking nothing. So there is no other rating I can give it but a 1. We have a two minute record and I think I only made 2 or 3 small corrections, because the airplane had a tendency to climb, and that's all. This might have been caused more by slight change or slight error in trim than by the random input. So apparently we have the ideal gust alleviator built into this airplane. Ken reminded me that I rated the ride quality 1. However, to be consistent with all my other ratings, I must rate this an 8.5 which means that the airplane is just as good in rough air as it was in smooth air, but the handling qualities are the same. Therefore, we can't really upgrade this to a 1. I'm only rating it a 1 if I were to rate this just on its ride quality. For the overall handling qualities I must stick to my original rating of 8.5.

PILOT B
CONFIGURATION 62, SMOOTH AIR, 10 APRIL 1962

Short period frequency appears to be quite low. I think it has about a 3 second period. The damping is also on the low side. Moderately low. I'd say probably somewhate around 20 to 30. Well, let's make it 20% to 40%, somewhere in that area. The L_{α} is extremely high. I can honestly say that I can't really tell whether the angle of attack indicator is moving at all, even when I make a 60° bank turn. For about a 2 g incremental pull up, I can see maybe half a degree of angle of attack change.

But anyhow, I was having the greatest difficulty in choosing a decent gear ratio. None of the gear ratios I looked at were acceptable, even the one I'm flying now. Although it's the best of the lot, it certainly isn't the kind of airplane I'd like. At the higher gear ratios, up to about 60 (which is where I started), the control of normal acceleration is nil , practically nil . When you just barely touch the controller, there initially seems to be a delay in response, but once the airplane starts responding, oh boy, she sure goes. It's very easy to get from a plus, say 2 or 3 g's, back to a minus 1. This obviously would be completely unacceptable. I also looked at gear ratios down as low as 20. Here the stick motion gets quite large. The feeling of positive control is all gone. Also, you have the feeling that you are running out of elevator control. But even at that low gear ratio, I would consider my performance of the flight path control portion of the task as being quite poor. Ken, what is my gear ratio right now? Ken: 25. I could just as easily have picked 30 or 20.

Might be a little better, but I certainly don't like to see the rate of climb going from a plus 1 or 2 or 3,000 ft/min or even pegged from one side to the other, on occasion. That's about how bad the over control is.

You can make a 60° bank turn with this airplane. I wouldn't recommend it unless you can approach it very, very carefully. There's no problem with power. I haven't touched the power, since I started evaluating this configuration. So there's no question about recovery. However, the recovery could be quite uncomfortable because the acceleration response is quite high and I think you would end up in quite an uncomfortable situation, i. e., high g oscillation. Just not a good airplane at all. I would think this is an unacceptable airplane and I think that my ability to maintain g's or to stabilize at desired rates of climb was quite bad. I would say that it was probably worse than what I experienced in Configuration 61. Apparently, the short period frequency and the damping aren't too different between these two, but the L_α is from one extreme to the other and I don't like this end of the L_α range any better than I like the other. I think I again have to rate this 8. 5 because I don't really think it's dangerous as such. In fact, it's probably less dangerous with the high L_α than it is with the low L_α, because in this configuration you can certainly stop the rate of sink very rapidly and there's no additional task of power manipulation. Also, there's no restriction on the bank angle. However, with large L_α's you do have extremely high g responses which aren't good. I'm going to rate this an 8. 5.

PILOT B
CONFIGURATION 62, ROUGH AIR, 10 APRIL 1962

Well, there is no question that this is unacceptable. I just dumped the system. There is no question that this is completely unacceptable. It is only a question of rating it unacceptable or unflyable, and this depends on the definition of unflyable. I had no control over the acceleration and the acceleration amplitudes were as high as plus and minus 3 g's incremental. Well, that certainly is not anything you would want to subject an aircraft to. Also, in addition to that, the accelerations reversed very rapidly so the rates of changes of acceleration were very high. Of course, this is on the debit side. So I'm going to rate this a 9. 5. Well, I'm going to rate it a 10. I don't really see much difference between a 9. 5 and a 10 anyway. So I'm going to rate it a 10.

PILOT B
CONFIGURATION 72, SMOOTH AIR, 16 APRIL 1962

The short period frequency appears to be quite low. The period is at least 4 seconds, I think. The damping is moderate–40% to 50%. The L_α appears to be quite low. I've seen as much as 15° angle of attack on the indicator.

I think that we're getting down to a frequency here where the time lags are quite important. The pilot initially feels he has some instability. What I mean is that the pilot's input is evidenced almost immediately be a large pitch attitude change. The acceleration doesn't build up immediately. By attempting to fly or to maintain some desired pitch attitude, it's quite easy to over control especially at the higher gear ratios.

The control feels like a soft, loose spring. There doesn't seem to be very much positive control.

Everything has to be done to instrument reference primarily the pitch attitude and the rate of climb.

I started at a gear ratio of 150, went up to 200, down to 25, and finally settled at 40. With a gear ratio of 25, there is certainly less tendency to oscillate in pitch. However, I found that I was limited to approximately 2 g's. I gave a big, hard pull and all I could get was 2 g's. I felt that this was too low. With a gear ratio of 40, I think that I can get something better than 2 g's, but again it's certainly not taking advantage of the entire maneuver envelope of this airplane.

On the other hand, I find that I would want to restrict this airplane to a maximum of 45° bank angle because the airspeed control is quite critical. Power manipulation is very extensive. You can end up with very high rates of descent. Airspeeds can vary easily as much as 100 knots, I think, unless the pilot is watching it very carefully and he times his power inputs properly, and so forth. All in all, this is a pretty bad configuration.

I find that by restricting the bank angles to 45° I can do a fair job of flight path control.

The level of effort necessary for this is quite high. I don't know whether I should say that this is dangerous although I think that it can very easily be dangerous if the bank angle is not maintained within reasonable values – less than 45. You can get into a 6,000 ft to 10,000 ft a minute rate of descent very easily. Airspeed can go all to pot. Because I have restricted the gear ratio as much as I have, it would be very difficult to make a very sharp pull up. Not only difficult, but I think impossible. You just don't have that much elevator control.

The L_{α} is very low and it takes a long time before the airplane responds. This is evidenced also when trying to maintain altitude or if you make a change in altitude to arrive at the proper altitude without overshooting or undershooting. This takes a lot of judgement on the pilot's part as to when he should make his input and when he should take it out to start his recovery, and so forth.

I think that this is definitely unacceptable. I think that it's quite bad. I'm torn between two things here. One is, that I've restricted the bank angle and, necessarily so, I've restricted the gear ratio to something quite low so that I have some decent flight path control.

On the other hand, anything I do with this airplane has to be smooth and slow. I have to be thinking all the time.

I have to expend a lot of effort to fly a decent flight path and so forth. The results are quite acceptable. On the other hand, if I were to increase the gear ratio, then I would make my flight path control quite bad. I can't do large amplitude maneuvers very well, but I can do small amplitude maneuvers reasonably well with quite a bit of effort. I'm going to rate this an 8 because I think you can definitely get into trouble with this airplane, not from a maneuver stress standpoint but from a lack of recovery potential or lack of good altitude and airspeed control. I'm going to rate it an 8.

PILOT B
CONFIGURATION 72, ROUGH AIR, 16 APRIL 1962

The ride quality was undoubtedly excellent. I would probably have to rate this a 1 if the random input represents rough air and I sure like this airplane in rough air. Therefore, the handling qualities are the predominant factors and we would have to rate this the same as we did in smooth air which is an 8. The normal acceleration response was essentially zero–a slight wiggle which you could see once in a while. Pitch attitude changes were very minor. I make only 3 or 4 very small corrections. An 8 is the rating.

PILOT B
CONFIGURATION 73, SMOOTH AIR, 16 APRIL 1962

The short period frequency is quite low. The damping is only moderate. I think that this is quite similar to Configuration 72, i.e., the short period characteristics are quite similar. It appears to be about the same to the pilot. The frequency is quite low and the damping is moderate. The big change here seems to be the L_{α}. (I'm not sure whether 72 was the low L_{α} or not.) However, this is a pretty high L_{α}.

The choice of gear ratio was quite difficult. I started out with a gear ratio of 100. However, I reached a gear ratio of 10 and I still wasn't quite satisfied so we changed the gains on a couple of pots and we're now at a gear ratio of 75 which is roughly (I think) 7.5 with the first gains. I had to go to a very low gear ratio for g protection, even with a gear ratio of 100. Here I'm going to get into a little difficulty. When I talk about the gear ratio now, I will be referring to the gear ratio with the present set of gains rather than the initial ones. I think that if the gear ratio here were say 150 the over control tendency would be much too strong and I think that you can overshoot the g's by as much as 1 g very easily. Even with this gear ratio (as low as it is) within the 60° bank envelope, it's quite easy to overshoot the g's. You can sit there and oscillate back and forth .2 or .3 g quite easily. You can't fly this very smoothly with respect to g response. Also, one of the reasons that I think this is so is that the stick motions are too large and the stick forces are too high. I don't particularly like this at all. However, I can do a fair job of flight path control with this gear ratio.

Pitch attitude presentation probably could be expanded and it might improve the situation, but there isn't too much that the pilot can see in pitch attitude changes. There is some, but

it would be better I think if the pitch presentation responded a little bit (although this is not as bad as I've seen in some configurations which are much worse with respect to pitch presentation, but this is a minor point).

I think that the thing that gives me the biggest trouble-what's causing most of the piloting control problem-is the very low frequency coupled with the quite high L_α.

Incidentally, power changes were nil throughout this configuration and this is something that is generally true with high L_α configurations.

I think that I'm going to rate this unacceptable. I think that I'm just going to rate this bad. I don't think that you can get into too much trouble with this. It's certainly going to be an uncomfortable ride if you try to make rapid maneuvers and you will get quite a bit of g oscillation. The rate of changes of acceleration is not very high, so I don't consider this very bad. I'm going to rate this a 7. This is the same type of thing that I had in Configuration 71. I couldn't really make up my mind whether it should be a 7 or an 8. I'll call this a 7 with leaning toward the 8. It all depends on how much I'm willing to tolerate in the g oscillation or the g overshoot or whatever you want to call it. I'm going to rate this a 7.

PILOT B
CONFIGURATION 73, ROUGH AIR, 16 APRIL 1963

The airplane responds fairly mildly. The normal acceleration response is generally around ±.2 with occasional responses of .4. The main reason that I say it's a mild response is that the rate of change of acceleration is quite low so that I think that the frequencies involved are easier on the human body. I guess that this type of response is what you might expect with a conventional type airplane in moderate turbulence. I did try some turns and I found that I had quite a bit of difficulty trying to maintain reasonable g or steady rate of climb when trying to make a level turn. I'm going to downgrade it just a hair with the thought in mind that if it were a little less responsive I would accept it without penalty. However, it isn't much worse than you might expect with a conventional airplane in moderate turbulence. I'm just going to downgrade it primarily on the basis of the additional difficulties I have in turns. I think that the poor characteristics of the handling qualities are more noticeable with the random input in that you do with the smooth air. I'm going to rate this a 7.5. As a matter of fact, if I had seen this configuration with the random input in before, I probably would have rated it about an 8 to begin with. I'm going to rate this a 7.5.

PILOT C

CONFIGURATION 3, SMOOTH AIR, 10 APRIL 1962

The airplane in trimming is – in trimming at one g, there are difficulties which are inherent in the configuration in the sense that pitch angle is not quite flight path angle, but about one g flight, you learn the configuration and you know that if the rate of climb is, for example down, that you make a nose correction and then put the nose back down to the reference attitude again and cross check with the rate of climb. It is kind of almost a pulsing of the elevator control – not really a pulse. Anyway that you hold long enough to make a small change in flight path and then return your attitude back down to approximately the same thing, making a small correction on the steady state pitch attitude. So the problem is that as you make these changes at constant throttle and the airspeed bleeds off, and therefore the rate of descent, for example, for the given pitch attitude increases. And so you have to, with this configuration, fly with the throttle and the elevator together. You have to be aware of the fact when you call for an angle of attack increase, that you have to have a certain amount of throttle and the amount of throttle that you had depends on whether you are going to produce another flight path angle or not and also how long you are going to have this angle of attack. So, it is a trial and error process. You have to look down at the throttle to see how much I have in. I say again, I would like to have some indication of the throttle position or thrust or something presented to me on the panel.

The gear ratio I selected was 400. And I selected this as a compromise based on the initial sensitivity to elevator inputs in terms of pitch rate (apparently due to the low L_α that we have here). This makes me pick heavier values of elevator force, whereas the elevator or force required to pull g's I might want lighter forces. So I have tried the full range, and I think what I end up with is a pretty good compromise. I don't feel having flown it that changing my elevator forces or the gear ratio would have any effect of improvement on the configuration.

Is attitude control satisfactory - actually it is not too bad. It is not real precise, but once again this configuration probably is not as sensitive to small attitude changes as some of the other higher speed configurations I have flown. The low L_α gives me some problem, making the airplane very sensitive to my initial control inputs, but if I smooth my inputs carefully I manage to maneuver. However, it is always present. What I observe is that when I put in elevator steps, the nose responds initially very rapidly. It does not actually seem to reverse. It is just that the maximum pitch rate that you get is so much larger than the steady state, fair amount larger than the steady state. This looks almost like the nose almost stops, but it doesn't really if you look carefully. I would say attitude control was only poor to fair. It will make it a little closer to fair. The reason response to controls is as good as it is is that the short period is well damped and moderately stiff. This helps a whole lot in this configuration.

Normal acceleration control a problem – no, it isn't. My only problem here is that the departure of normal acceleration from unity means that there will come about a very significant change in airspeed. Therefore I don't use normal acceleration as much in this configuration as in others. Pitch attitude display gives me information about what I need. Pitch attitude and rate of climb give me the information of what I need in the way of correcting inputs. Attitude is so responsive during the corrective inputs that I tend to watch it. About 12° angle of attack produces 1 g. This is a big change in α and for constant throttle the speed change in tremendous for this one g. So I just don't ever use one g, unless I am really getting off with the throttle. So basically the accelerations are so small that the accelerometer is not a very useful instrument. I say that normal acceleration control does not seem to be a problem except for the fact that because with acceleration comes airspeed changes and this does cause a problem.

Factors entered into your selection of gear ratio - I discussed it.

Can I hold altitude - I find it fairly difficult. This is a configuration where in level flight I can hold altitude fairly well because I am only calling upon very tiny changes of normal acceleration about unity. Therefore airspeed control is not a problem in level flight for the small inputs that I am using. This is not so bad, but boy, in turns I have problems. For one thing, the pitch attitude for level flight at 215 is certainly a definite function of the bank angle. So I have to fish for this. The airspeed is the function of the bank angle in g's. So I have to fish for this. I once in a while get into a sink where I don't have enough power for the g's or angle of attack that I am carrying. The airspeed bleeds, that causes the g to bleed, that causes the flight path to descend more steeply. In other words you get into a real big hairy sink, and nothing cures it except lots of power and if possible, use angle of attack. You can't pull much g with the usable angle of attack range. Well, it is a problem.

What bank angle range is usable - I used up to 45°, but I wouldn't recommend it. I felt that it was comfortahle up to 30° bank angle.

Maintaining airspeed is a problem - as I have already stated, it was a considerable problem. Airspeed control was fundamental to this configuration. You need a real tight feedback on airspeed. I think that my airspeed control was fairly good; but any time I had trouble with the configuration, it seemed because the airspeed was wrong for what I was trying to do.

Special piloting technique required - yes, in the sense that real tight airspeed control, using the throttle as a primary response to airspeed. Other things that require special techniques with the low L_α , you have to be consciously aware of the fact that the pitch attitude does not give you flight path angle, change your technique accordingly. You have to smooth your initial inputs pretty well or else recognize that the initial response you get in pitch attitude is not representative pitch rate of what you have if you wait a minute. If you make an angle of attack change, you have to be sure that you come on with the throttle. I just did.

What instruments am I using most - I would say attitude, rate of climb. Those are my primary instruments. Oh, I am sorry. Attitude, rate of climb, and airspeed - right across the row here. Cross check with the altimeter, the heading instrument. Occasionally look at angle of attack. Occasionally look at acceleration - accelerometer.

Any instruments inadequate - I don't think so. I will just comment that the fact that you have to look at different areas of the instrument panel to get these fundamental quantities that you need to control the configuration precisely does hring about - introduce some difficulties. I would like to see for example - I think I would see as I have said before maybe flight path angle on my attitude indicator, horizontal bar, maybe some way put airspeed on that too around the outside. That would help, I believe. I think I have talked about just about everything.

The altitude changes I have not talked about yet. The ability to hold the given rate of climb or rate of descent was, I would say, fair to perhaps - well in straight and level flight - in non-turning flight, in straight flight it was fair and in turning flight it was poor. I could not fly rate of climb. Oh, I could, but you couldn't do it very precisely. You would oscillate above and below the desired rate of climb. The easiest way seemed to be to make the attitude change necessary to produce the given rate of climb change and then bring the attitude back to reference attitude and come on with your additional throttle, if you were actually changing your rate of climb or rate of descent. And if you wanted, you would have to come on with a little bit of throttle to make up for the fact that when you change the angle of attack to change the rate of climb that you lost a little airspeed.

I have been wondering for a long time here what I would rate this configuration. Let's start off by saying it is not unflyable. It is not in the first category of acceptable and satisfactory. So it is either in the second, acceptable but unsatisfactory, or the third which is unacceptable. I don't really know quite where to put it. I don't know what the mission is. I would say that for perhaps a landing approach or something like that, an ILS, that it would not be too horrible because I would be in straight flight most of the time like an ILS final in straight flight. And I would be able to manage the configuration fairly well. However, if I envision my turning maneuvers on instruments and require precise altitude control, I find it very, very difficult. This is one of these configurations that you have problems with. For small disturbances it is pretty good that when something starts to go we are off, particularly with regard to airspeed or flight path angle. In other words when the flight path angle gets away from you, it really goes down. It can set up a terrible sink rate in a heck of a hurry and you really have a can of worms. For this reason I would call it unacceptable. And so it was principally based on this problem of the likelihood of a very high sink rate that I categorize it as unacceptable. And I think this is perhaps a situation that there are airplanes I'm sure that have these handling characteristics. Particularly, the low L_α , possibility of getting in these high sink rates. I started to say once upon a time that there were areas in which the F-86 felt like this. This may be a little bit worse than it is, but you can certainly - I think it is worse than the F-86. I don't know of any area where the L_α is quite this low. But on approach when you are slow and heavy, this begins to feel a little bit like it. You can set up these tremendous sink rates. And the answer to flying your configuration is active throttle control and lots of it. I feel that the short period characteristics were so good that they make this configuration flyable. Therefore, I would not put it at the bottom of the unacceptable category. I have been trying to remember here that we have said you do not want to penalize the configuration for inherently low g producing ability. This is a flight condition and I don't want to penalize this configuration for this. But you sure do have problems with it. I will rate it a 7.

PILOT C
CONFIGURATION 3, ROUGH AIR, 10 APRIL 1962

The g response was negligible. In that regard I would say that it was very good in turbulence. However, there were I would say that the pitch disturbances were large by comparison to anything I have seen today. I don't know whether this is principally due to the speed or whether it is – I know it is due to L_α among other things. The airplane was disturbed to quite large magnitudes in pitch. However, I felt I had fairly good control in pitch to collar these disturbances. Everything was a little oscillatory. In other words when I put in a controller to counteract the pitch motion I had the feeling that it was rather sensitive, too much response to my inputs. By the same token the disturbance – the most airplane pitch motion following the disturbance was very sensitive and fast responding too. All in all I noticed that the g was a good ride, an excellent ride. Pitch attitude you would be rocking back and forth quite a bit. Here you would be fairly effective in minimizing the pitch disturbances.

My altitude disturbances were negligible. Altitude deviations were less than probably 60 or 70 feet. Therefore, I would rate this pretty good in turbulence.

I would like to see it have less of this nose disturbance, pitch disturbance, pitch response, but maybe if I got that I would have more g. I don't know. I consider it fairly good. I don't think I would downrate it. This is the first configuration I think I have seen though that any possible degradation in opinion during the rough air maneuver would be due to the attitude response rather than the g response, the actual controllability. I think that of the things I have seen on this configuration, the thing I object to is the magnitude of the g - serve a ride - or whatever you want to call it. I would almost be tempted to lower my rating a little bit just to show you that there was not objectionable characteristics, but I have already said there was a number of objectionable characteristics. I don't really feel - well I was surprised a little bit to notice the large amplitude of the pitch disturbances in the rough air. But I was also impressed with the very fine riding capabilities. So I think the two counteract each other and I will not change my rating. I think I will still rate this a 7 in smooth air as a good characteristic of an excellent ride, the less that good characteristics of relatively large amplitude, pitch attitude response, in turbulence, and only fair controllability in minimizing pitch attitude disturbances. I think they kind of average out the other and I will not change my rating. I will rate it a 7.

PILOT C
CONFIGURATION 3A, SMOOTH AIR, 18 APRIL 1962

This configuration has a low L_α . It looks like about 12° angle of attack to pull 1 incremental g. The airspeed is 250 knots. The gear ratio I selected was 450, I believe. The short period characteristics looked to be moderate frequency and a damping ratio of perhaps .7 – in other words it looks almost deadbeat. There might be a very, very slight overshoot but it's deadbeat for practical purposes.

The configuration required considerable airspeed monitoring and a fair amount of throttle changes.

The configuration has some good qualities, and yet it has some objectionable qualities. It seems that the - first of all, it's objectionable from the standpoint of its inability to pull much in the way of g's. You're limited pretty much to a 60° bank angle because you really can't pull much more than 1 incremental g. This gives at least 12° angle of attack. Airspeed proposes a great problem. I don't think that any of the larger g's are feasible – they're possible but not feasible to use. Heading changes at constant altitude go fairly well up to 60° bank angles, then I had difficulties.

If I held my airspeed constant, I seemed to fly a fairly level flight. If my airspeed gets away, I notice that the g's and airspeed for constant stick force go right hand in hand. Any bleeding of the airspeed causes me to have less g than I intend to have and consequently, my flight path bends downward and just the opposite is true for speed increases when I have too much throttle on.

The airplane, I'd say, trims moderately well. I didn't have any real great difficulty.

Attitude control is on the borderline – well, it's not very satisfactory. There's a definite tendency to bobble the airplane when making quick pitch corrections. It's difficult to pin

your pitch attitude down when you're trying to hold a steady turn. I say it's difficult because each bank angle demands a different pitch angle to maintain level flight. If you have errors in your bank angle and you're trying to hold a given pitch angle, then you find that your rate of climb is considerably off. I don't think that attitude control is very good in this configuration.

Normal acceleration control is good at constant speed. I'd rate it as good on constant speed. It could be stiffer and have a little less lag and it would be better. This is certainly satisfactory and it's fairly good. However, I qualify those remarks by saying at constant speed. The problem is that as my speed varies so does my g. This does give me trouble. So I would say that normal acceleration control due to normal short period characteristics is pretty good, but normal acceleration control counting the whole is not so good. Basically the airspeed tends to drop off and my ability to control acceleration is largely dependent on my ability to control airspeed. Flight path control is only fair to poor. For small bank angles, it's only fair. For larger bank angles, it becomes poor. At level flight, I'd say that it was fair to good in the sense that I can maintain my rate of climb and rate of descent half-way decently.

Factors entering into my selection of a gear ratio were a compromise between forces required to maneuver, or forces required in a steady turn, and the initial response to my force inputs. The attitude display shows initially my angle of attack response in effect, and as you increase the gear ratio it becomes too sensitive. I settled on that value of 450 as a compromise between the two.

Can I hold altitude straight and level? – pretty well, turns not so well. It pretty much depended on my airspeed control.

What bank angle degrees are usable? I don't think that 60° are very practical, it requires very large throttle. If you had less thrust available than this particular simulator does, then certainly you could not use 60° bank angles.

Is maintaining airspeed a problem? Yes, it is as I have discussed.

No special piloting technique required. Basically the one that seems to work best is to fly attitude and cross-check on the rate of climb.

Instruments I'm using most – attitude indicator, rate of climb, airspeed, altimeter and so forth and so on - angle of attack occaisonally – in that order as I've just described.
The ones that I'm using most are the attitude indicator and the rate of climb and airspeed.

Any instruments inadequate? I think not. I would like to see flight path display on the attitude indicator. I think that would help perhaps.

I consider the configuration generally acceptable for a generalized mission. My philosophy has been if the L_α is somewhat inherent.-- I mean the inability to pull g's is inherent with the L_α – and therefore I wouldn't downrate it because of the inability to pull g. However, the low L_α apparently has a detrimental effect on my ability to maintain precise attitude and flight path control. I would say that the effects are such as to make it unsatisfactory although not overly so. I believe that I would rate it a 4 in the smooth air. The word fair seems to describe it pretty well. The saving feature of the configuration is the moderately good short period characteristics. In other words, they tend to make me rate it higher and the L_α tends to make me rate if lower. I have compromised on a rating of 4.

PILOT C
CONFIGURATION 3A, ROUGH AIR, 18 APRIL 1962

From a ride standpoint, I'd say that this was a very good configuration if you watch the accelerations which are very, very small. Most of them don't exceed .1 g.

However, the pitch attitude disturbances are considerable. This is bothersome. Furthermore, the pitch attitude changes required to reverse the direction of the rate of climb are tremendous. In other words, if the low frequency content of this turbulence is like you would expect any turbulence to have. If you try to maintain constant altitude, which I was certainly trying to do to some extent, you have to make large changes in the magnitude of pitch attitude about which you are trying to know the higher frequency content of the noise. In effect, you have an attitude loop that you're stabilizing and then you have a flight path loop too. At times, they're contradictory to each other. In other words, you have to get off in attitude in order to get your flight path back. These are relatively large changes in terms of pitch attitude. They amount to maybe ±3° and that I consider to be considerable.

I did not like the configuration as far as its controllability in rough air. I did like its ride. I expect that the pitch attitude disturbances would be somewhat objectionable in rough air, particularly for a passenger.

Now I have to rate it. I had the feeling that seeing the configuration in rough air, I had been too generous in my rating in smooth air. However, that's already given. I'm afraid that I can't rate this any better than a 6. I must confess that I considered rating it down to 7. This involves going from an unsatisfactory category to an unacceptable category and I don't think that I'm really willing to do that. In other words, I think that this airplane can be flown. It can be flown for thirty minutes with no problem in rough air. I don't want to fly it very close to the ground with these handling characteristics. And how close you start talking about determines whether this thing crosses the boundary between unsatisfactory and unacceptable. Certainly due to poor altitude control, it is an unsatisfactory configuration. If the demands of altitude precision in altitude flying are really severe, like if you're down at 500 feet or lower, then this is an unacceptable airplane. If you're just talking about relatively low altitudes, then it's a rating of 6. In effect, I guess I'm right on the border and maybe I should make it a 6.5, maybe I should make it a 7. The altitude control is very poor, and this I must emphasize. During the two-minute record, my altitude went as low as 300 feet below what I was trying to fly. I didn't try to fly a real tight altitude loop. I would have done somewhat better if I had. I was trying to compromise between flying a good attitude loop and a good altitude loop and I consequently didn't do a real good job on either one. The more I set here and try to fly the thing, the more I'm convinced that it isn't even as good as a 6. I think that I'll rate this one a 6.5.

PILOT C
CONFIGURATION 4, SMOOTH AIR, 10 APRIL 1962

Got another one of these low L_α , low speed (250 knots) airspeed configurations. This one differs from the last one, I think, by being a higher frequency short period. Still quite well damped, lower L_α . The tighter short period seems to give me a better rate of climb control about a stabilized rate of climb. In other words, if I'm trimming up for straight and level flight and have the power set and everything properly, then I can fly level flight fairly accurately as long as I track rate of climb carefully. The same way in a climb or descent, say at 2000 feet per minute. Once I get stabilized on the 2000 ft/min and have the right throttle in for the airspeed and everything, I can control the rate of climb real accurately and I'm beginning to see that accurate rate of climb control apparently goes with good short period characteristics. I mean fast and tight. That's only a small thing in favor of this configuration, because then I think you can stabilize it for small disturbances.

This is a pretty good configuration, but to try to fly it, it has too many maneuvers involved. Flight path angle changes and the attendant speed changes. This is a pretty miserable type configuration, very low L_α . I pulled 15° angle of attack at 250 knots and I got about .4 g, something like that. I didn't pay that much attention, but the main thing that happens if you try it is that you sink like a son of a gun. It's a real nonlinear type of configuration. In the similar fashion to the last one, i.e., when you pull high angle of attack, you just start to sink and you have to be on the throttle and on it with the right amount at the right time. If you get too much throttle in, then you go the other way. You climb, your airspeed builds, and get a hair too little throttle, then you're on the backside of this power curve and you really sink much faster. The airspeed bleeds much faster and everything. So if you miss putting on the right amount of throttle by just a little bit on the low side, then things go to pot in a hurry. Consequently, I find myself both in this configuration and the last one, having a tendency to fly at airspeeds above 250. Because whenever I get right down to 250 it's a real poor situation, as far as controllability of the flight path, with the likelihood of encountering the high sink rates. There is nothing in an airplane that is any more discombooberating than a high sink rate especially close to the ground.

I selected a gear ratio of 500 I believe. I tried lighter, then tried it heavy. This gear ratio is selected entirely on the basis of attitude changes. I didn't even consider g. Well, I guess I did consider g a little bit because I did consider flight path changes, and that would be g. But I think the lightest forces consistent with good attitude control and I pick the lightness so I can change the flight path with a minimum of effort, and consistent with good attitude control.

Turns – boy, I'm lucky if I can fly 30° bank angles and I wander all over the sky. Once things go, get out of your controllability range and your precise control ranges, then you have to make such gross throttle or elevator changes, your altitude goes to pot, your airspeed goes to pot, and everything goes to pot. So – usable bank angles – I don't even think 30° is very usable. You actually have the throttle available to do it, but for precise control you probably want to use more than 20°. If you can even define precise control for this.

Altitude changes - once you're on the rate of climb you can do it. But to get to the right rate of climb is a real problem. Very poor correspondence between what you see on the attitude indicator and what your flight path is. I found that I was able to do a little better job if I cross-checked real rapidly when I was trying to change my flight path between my pitch attitude display and my angle of attack display. As a matter of fact, I was trying to take the difference between the two and guess where my flight path was. I tried that in comparison with rate of climb control. Now rate of climb control doesn't seem to work too well because if I'm watching it, I don't know precisely what my angle of attack and pitch angle are, all I know is what my flight path angle is. Whereas if I'm watching pitch angle and angle of attack, then I know each of those separately, plus therefore, I know the sum. So this appears to be something of a deficiency, this rate of climb control, as an instrument indication of flight path angle.

So is the airplane difficult to trim? Yep. I meant it's difficult to trim because of the lack of correspondence between attitude and flight path. It's difficult to trim because if you start to sink and you got to come on - well, let's say you're about at the right airspeed and you're about at the right throttle setting, but you get an indicated rate of climb down, so you increase angle of attack and the pitch angle and if you don't do anything on the throttle you just sink faster, and if you get after it with the throttle, then you lose your correspondence with what you had in throttle position for that airspeed before. I don't know, it's a mess. But you can't trim it up. I don't mean to say you can. It's just not a good configuration. Good short period characteristics are healthy. It's the other things that give you problems. Low L_{α} is the main thing.

Is attitude control satisfactory? I'd say it is fair, but it is good from the contribution of the short period. In fact, I like that. But for the low L_{α} yawing causes the large sensitivity of for small inputs, which really isn't too bad because I selected a gear ratio to be such that I can handle that. But there is a big difference between what you initially put in and what, if you're going to hold it for very long, what you finally end with, but it's not too bad. I'd say the attitude control probably is fair.

From the acceleration control, I don't even control normal acceleration. So I don't know how to answer that, but flight path control is terrible. I mean that is is unacceptable.

The fact is, I selected then a gear ratio that I discussed.

Can I hold altitude? I can hold altitude straight and level once I'm in straight and level flight, fairly well - I wander. I find that if I fly tight in attitude, this helps. Now I don't mean that to fly in attitude alone, but between attitude and rate of climb in level flight and I have a rate of climb error, if I make a change in attitude, until the error is gone and then go back to my original attitude or near to the original attitude. Keeping the throttle coming on as necessary, then I can hold altitude, but not very well.

Turns much more poorly. I think it's because I'm distracted more. I'm having to look at more instruments. I've got more to do and therefore I can't be as tight in my closed-loop control. Bank angle range usable - I did discuss that. 30° is usable, but I prefer not to use more than 20°.

Maintaining airspeed a problem? It sure is.

Is special piloting technique required? Yes - I think I described them fairly well.

What instruments as I using most? Attitude, rate of climb, angle of attack, airspeed, interchange - let me see now, attitude, rate of climb, angle of attack, airspeed, cross-checking with the altimeter. And of course, having g's is kind of information instruments, very secondary.

Instruments inadequate? No - except their locations are. I still say I'd like to see the flight path angle, or something like it, displayed on the attitude instrument, and airspeed close by throttle position.

When it comes to rating this configuration, as far as I'm concerned, there's no question but what it's unacceptable. I find it difficult to classify in unflyable because I don't know what the mission is. If you ask me if I can land the configuration, I think I could on a nice smooth day, if I got it all squared away on final, nicely set up. But it's a pretty miserable sort of thing. Another thing that makes it unflyable is all this throttle I have - all this thrust - it's very helpful. If I had any less, it would be very, very dangerous. It is dangerous. I just only give it a rating between say, an 8 and a 9, and it's very bad. I think

I'll call it a 9. It's almost 9.5 in the sense of defining a 9.5 as being 'I don't want to fly it if it's any worse'. So I'll categorize it as being either a 9 or 9.5. With this amount of throttle, I'll call it a 9. Give me any less throttle and I'll call it 9.5.

PILOT C
CONFIGURATION 4, ROUGH AIR, 10 APRIL 1962

Ride excellent. Controllability pretty good. I wouldn't change my rating. I think my controllability is probably a little better than it was in the last configuration. In the rough air, I'm not sure of that. It seems to be a little better. I think the tighter short period must have helped. I'll rate it a 9 still. I'm not going to make it any better because all those problems are still there. But I don't think it's any worse.

PILOT C
CONFIGURATION 7, SMOOTH AIR,

Basically this configuration is easy to trim. Good in straight and level flight. At this speed, you get a lot of pitch rate for your g.

The response to elevator steps is basically - your controller orders the steady rate. I looked carefully and I can't even detect that the rate of change is nonlinear or this is the nicest range that I get, whenever I put in an elevator step and it comes in very rapidly.

Short period frequency is moderate. Damping is good. I'd say the damping ratio probably is about .7. The stiffness or response time is approximately 1 second, or something like that. The L_α is - I don't know what you'd call it - well, I'll describe it this way. From a maneuvering standpoint, I think this is the best configuration I've seen at this speed. If I had to say what I'd do to make it better, which I obviously don't know, I might like it at least in the simulator if it was a little stiffer. If I had a little higher frequency short period. The L_α sure looks good. It does.

I have no objections to my pitch dynamics. I think they are - I mean what I see on the attitude indicator is straightforward and predictable.

My only trouble with the configuration is that I do have a little trouble controlling rate of climb if I try to control it directly. Now that isn't a real valid criticism of the configuration because I doubt that you'd have this good a rate of climb instrument in an airplane and therefore, you wouldn't be able to use rate of climb as a primary control instrument anyway. But it is a difference that I notice here.

But due to the speed, the pitch attitude changes that I get in order to have a certain rate of climb up or down, the pitch attitude changes enough that I can control my rate of climb very accurately by controlling pitch attitude. So I really have no difficulty with the configuration in that regard. I can control rate of climb accurately by controlling pitch attitude accurately and small changes in pitch attitude produce only small changes in rate of climb and therefore I'm able to do it accurately.

Speed control - there's very little difficulty. I do have to add a little more throttle when I go into steep turns of 1 g or 1 incremental g or more. But once again, it's no real problem. Basically this is still an elevator control type of airplane.

The altitude changes - of course, flying altitude with this configuration is much easier because you're going slower and small things don't happen as fast with pitch attitude here in terms of rate of climb, and therefore the resultant altitude changes are not as great. I had no difficulty with the altitude changes or the climbing or descending turns.

I had no trouble with turns in general. Holding altitude is very easy. It is one of the easiest configurations perhaps for holding altitude.

My only question from a couple of minutes after I got the configuration until now is whether to rate it a 1.5 or a 2. I don't think the other characteristics of the airplane - the lateral-directional, etc., would merit a 1. So this is what I'm deciding between. It's a good, good to excellent type of airplane. Now as to the questions.

Is the airplane difficult to trim? No. Easy.

Attitude control satisfactory? Yes.

Normal acceleration control a problem? No. I possibly might like it a little faster responding in acceleration, but this is sure good.

What factors enter into the selection of gear ratio? Well, it was a compromise between the sensitivity in pitch attitude and the acceleration that - the force required to hold 1 incremental g. I found that both I had to weight. I think if I got stick forces per g very light, then I wouldn't have too precise attitude control that is required for this configuration. It would be too sensitive. Therefore, I chose a little heavier. The gear ratio I chose was 75 I think.

Can I hold altitude? Yes - straight and level and in turns. I can hold it and hold it well.

Bank angle range usable? All bank angles.

Special piloting technique required? No.

Instruments I'm using most? Attitude, very definitely attitude and acceleration - cross-checking of climb, altimeter, airspeed occasionally. It's not much of a problem.

Instruments inadequate? No I don't think so.

Real good configuration. I have to rate it a good to excellent configuration. Well, I'll tell you what. I would rate it a 1.5 except for the fact that maybe you could make it a little better if you stuck in that little stiffer short period. So this is one of these that I'd call a 1.75, but nobody will let me. I want to allow for something a little bit better without having to go to a 1. So maybe you can understand my problem. It's better, I think, than some I've rated a 2. I'll try a 1.5 for this configuration.

PILOT C
CONFIGURATION 7, ROUGH AIR

This is a peculiar one. First of all, the pitch attitude disturbances due to rough air were very large. I found the controllability of the configuration very good in minimizing disturbances in pitch attitude. However, the excursions in rate of climb were very large when flown in constant pitch attitude. So actually during the record I changed my technique considerably. In the very beginning I flew constant attitude and then I went to a period where I flew - I tried to fly - constant attitude and constant altitude, and then I ended up flying constant attitude again. These are different. In other words, I detect a rate of climb and then I try to produce pitch attitude which would counteract that rate of climb and therefore, I'd be maintaining altitude, and about the time I'd get the pitch attitude change necessary in order to get the rate of climb back to zero, the disturbance would go into the other direction. So I feel sure that the proper technique for flying this configuration is maintain a constant pitch attitude and accept the flucuations in rate of climb. Just try to average them around your altitude. In that respect then, the configuration is pretty fair except that the ride is considerably unpleasant.

Now I'll have to rate this and you understand there's a large degradation in opinion due to the large accelerations that are exerted upon the pilot in this environment with this configuration. I feel like I'm just guessing when I guess at the level, but I saw accelerations as high as 1 incremental g. Most of the time they were of the order of .5 incremental g, but on the plus side of .5. They were slightly larger. This is a pretty darned rough ride.

I think I would categorize it as acceptable and unsatisfactory probably. I think I could last 30 minutes, but boy, I think you'd want to do something about it. The basic handling characteristics of the airplane are very good, so I don't really know how far down to rate it. I been generally using the classification that if the g's didn't exceed one, and most of them didn't exceed around .5 to .6, I would put it in the acceptable, unsatisfactory category. Therefore, I'd say this is something like a poor and maybe I'd rate it - I'm trying to be consistent. I'm not sure that I'm right. I've talked to the other pilots a little bit and I feel that I'm basically wrong in my judgment of the ride, but once again, I'm trying to stay consistent. So I'd judge this to be poor or bad from the ride standpoint. There's very good controllability, though. The speed brings about large pitch rates though. It's inherent. You've got good control of pitch attitude. I'll rate it a poor. That would be a rating of 5, and you'll have to understand that I'm - I would have rated it a 6 except that the other characteristics were awfully good.

PILOT C
CONFIGURATION 15, SMOOTH AIR, 11 APRIL 1962

Airplane was fairly easy to trim. As I remember I didn't have too much of a problem. We've had some problem with the altimeter, but it did not affect my evaluation, I don't think.

This configuration is one which exhibits a lower L_α than the previous configuration, but the short period dynamics look very similar. I'd say it's a moderate short period stiffness, frequency, and something about .7 damping ratio. L_α I would judge was probably in the order of twice - or half I guess it would be - half the last configuration. So if I had to guess, I'd say this one was the last configuration with 1/2 the L_α. This is relatively unimportant.

I'm not making decisions based on this. But the things that are noticeable here are that I have more trouble with this configuration in flying attitude, a little bit more trouble flying flight path, and I certainly have more trouble holding airspeed. All these increased difficulties are subtle. In other words, my initial reaction to the configuration was that it was a 3. And the longer I've been flying it, my rating has moved up and I'd say right now, between a 2.5 and a 2. The reason for this improvement, I'm not real sure. Perhaps as I do the different tasks I notice I can do them fairly well and therefore, this improves my rating. I really don't know what the cause of my improvement in opinion. I keep accusing Ken of changing the configuration, but actually I had the feeling in the beginning that perhaps it had a slightly lower L_α than it does now. But that is not a scientific observation, it's just a feeling. I don't really honestly believe that it is any different now than it was in the beginning.

So I think airplane trims up okay, straight and level portion all right. As far as pilot-initiated disturbances, it feels like a pretty fair type airplane. Trouble with elevator trim now, wonder what's going on. Guess it's my airspeed.

Well, usable bank angles are not as large as the previous configuration. I can go up to 60° bank and have plenty of throttle. I can pull 4 g's, but I really go through quite an angle of attack range to do it and it feels a little more uncomfortable than the previous configuration and it also feels that I can do it a little less precisely.

But my precision decrease seems to be more in pitch attitude than in angle of attack or g. So degradation in my control in pitch attitude and also my control of airspeed, and due to the slight degradation in pitch attitude control, my rate of climb control is also not quite as good in areas where I'm changing pitch attitude.

I find I can set up a rate of climb, or steady rate of climb, and steady rate of descent pretty accurately. I know the other configuration was good in this regard, and this one basically is too. For small changes I can hold the rate of climb fairly accurately. The slow speed causes the airplane to have a small change in the rate of climb for a given area of pitch attitude and consequently really all I have to do is control pitch attitude pretty closely and I can control rate of climb pretty accurately. So in that regard, this is a pretty good configuration.

Where I seem to get into trouble is where I'm changing pitch attitude - there's a little bit of difficulty.

The altitude changes have been all right and the climbing, descending turns, as long as I was in a steady state condition in making small corrections about it, I was all right. But if I wanted to roll between a 45° bank and a 60° bank, maintaining level flight, I had a little bit of a problem, because I'd have to change my pitch attitude a little bit, apparently due to the low L_α, as I was pulling g's. So read through the comments of the airplane.

Is the airplane difficult to trim? No, I'd say it's pretty fair.

Attitude control satisfactory? Satisfactory, but not as good as some, but better than others. So it's a little less satisfactory than, for example, the last configuration in this regard.

Acceleration control a problem? No, except tnat I had to perform quite a rotation for a change of g's. Not quite a rotation, larger than the last configuration rotation.

Factors entering into selection of gear ratio? Compromise between sensitivity

in terms of pitch rate that I get for a given controller, ability to resolve small pitch attitude changes - compromise between that and the stick force per g. Probably picking a little on the heavy side in the stick force per g, but not too heavy. I think this is a reasonable gear ratio. I think I decided on 150.

Can I hold altitude? Yes - straight and level and in turns. Once again I do much better in my altitude control during steady turns and steady level flight than I do on my rolling out. I'm coming to the conclusion that the side controller enters into this.

The side controller is not very good for putting combined pitch and rolling inputs. We've discussed this before. I would say that when you have a configuration with low L_α , this becomes a problem because when you are rolling your steady 60° bank turn, pulling 1 incremental g and you have to roll back to level flight (to zero bank angle) you also have to take out this large angle of attack that you may have. You might have from 5° to 10° of angle of attack to pull that one incremental g. So that's 5° of pitch attitude, almost 5 to 10°. You've got to take that off, in other words, you have to actually push the nose back to level flight as you're rolling, and this is a problem with the side controller. I don't do this very successfully.

I also have noted on a number of these configurations that the aileron control is pretty darned sensitive. I think I commented on this before. I wouldn't doubt but what we can do it at a lot lower gear ratio on the aileron than these configurations. I notice it more about when I'm in a 60° bank angle. I think maybe this is what the other pilot has talked about in wanting to be able to lock the ailerons in. I don't think that's the answer, but I think perhaps a lower aileron sensitivity is the answer. If you want to make a small correction in bank angle when you're in 60° of bank, in holding 1 incremental g, you will invariably correct and make too large a bank angle change inadvertently, and as a result tending to roll oscillation (of course, when you do this inaccurately).

The airplane is very sensitive in terms of flight path to having exactly the right bank angle for the g's you are holding, so if you get off much in bank angle your rate of climb will go off and this gets you all fouled up. It would be interesting perhaps to do some low L_α configurations on this center stick.

Well, the bank angle range that is usable, I'd say up to 60°. I can pull more g, but you have to really get on the throttle then and I'd say that you can do it at 60° all right.

Maintaining airspeed is a problem, more so than the last configuration. You have to cross check with the airspeed frequently and it's no terrible problem, but you sure could use a power indicator on the panel.

Special piloting technique required? No, except that rolling out of a turn, you're busy trying to get it back to level flight.

Instruments I'm using most? Attitude and rate of climb, accelerometer, and probably

Are any of the instruments inadequate? The answer is no, I don't think so. So I have to rate the configuration.

I'm still not decided whether to give it 2 or 2.5 yet. I'm inclined to make it 2.5 I think more because of - well I'm not sure. Because it just is not a configuration that you can roll into a turn and really keep the rate of climb nice and zero, and yet you can do it with sufficient precision probably for most any sort of mission. You're kind of working at it and sometimes you do a good enough job, and you really begin to think it isn't so bad at all. But you really have to stay fairly tight on it. I think I'll rate it a 2.5.

PILOT C
CONFIGURATION 15, ROUGH AIR, 11 APRIL 1962

I don't know why I'm having so much trouble rating this configuration. There are times when I seem to like it real well and other times I seem to be having trouble with it. I don't know why the rather inconsistent performance on my part, but I'll try.

Describe random noise. There were lots of disturbances in pitch attitude and the disturbances in acceleration were, I'd say, moderate. There were occasions they would be up around .5 - .6 g. Most of the time they are down around the level of .1 or .2, say .2 - .3 of a g. So this is not a too bad configuration, I don't think, in turbulence. I couldn't call

it optimum, because I think probably an optimum configuration might be one that you'd have a gust alleviation system on and wouldn't have any response to turbulence to speak of. So once again this isn't too bad. My thoughts are kind of running around like a 3 or 4 rating.

I did notice that in turning maneuvers that the ... just naturally you'd do the way the turbulence was put in. The disturbances in pitch attitude become less, and I guess it's due to the cosine of the bank angle. It did look awfully good. My opinion kind of increased seeing it in a 60° banked turn. More than I was seeing the ... just the g disturbances and not the attitude disturbances you might think and I kind of found my controllability was pretty good.

The ride - I think I'd be pretty tired at the end of 1/2 hour and I don't like to say that this is very good from a ride standpoint, probably controllability.

I think it's pretty fair and acceptable and satisfactory, but from the ride I think it's probably not satisfactory and most of my opinions have been weighted on the ride aspects, so once again I get back to the rating of 3 to 4. I'm not real positive as to which I should choose. I think fair probably describes it pretty well. I'm afraid unsatisfactory is just a little better word than satisfactory. I'd like to see it a little bit better than this. So I'm going to rate it a 4 in turbulence. I think my previous rating was 2.5 in smooth air, and I'd like to make the comment that between configurations 7 and 15, my ratings show a degradation. I remember because I did one before lunch and one after lunch. My ratings show a change of opinion of one and I question in my own mind somewhat if that is really so. I know that I definitely prefer configuration 7, but I don't know that I prefer it by a whole rating up at this end of the scale. I don't want to change my rating, understand. I'm just looking back and putting it down for what it's worth. I wouldn't be a bit surprised if I did configuration 7 again, I might rate it a 2, and if I did this one again I might rate it a 2.5, so that perhaps one-half rating would be perhaps more descriptive of the difference. But this configuration 15 - I'm right at the edge. Things are starting to get a little bad due to L_α . I would think that this is what is causing it, and it's just that it is noticeable and the difficulties are noticeable there and are not just large enough – just noticeable but not too much of a problem. It was a little difficult to assess just how much of a problem they were. I rate it after the random noise a 4.

PILOT C
CONFIGURATION 20, SMOOTH AIR, 16 APRIL 1962

This is a borderline configuration between satisfactory and unsatisfactory. It's an acceptable configuration. It has a moderate short period stiffness - something like a two second period. Damping ratio of 30 to 35% of critical.

I selected a gear ratio of 120. I thought that I was selecting it a little on the heavy side because of the tendency to overshoot your desired g and the little tendency to bobble the airplane. However, in flying it longer, I don't think that I selected it too heavy at all. I wouldn't want it any lighter than this in straight and level flight. I've described the open-loop characteristics and in flying the configuration, you notice that it's a little sensitive.

You have a tendency to overshoot your desired g. The response to elevator steps is rather rapid initially.

The pitch attitude response comes to a halt and then goes on again. If you have a pitching velocity down, for example, and you reverse your pitching velocity with an elevator step, the nose responds initially rapidly and then it stops and actually reverses a little bit in pitch rate and proceeds on.

The value of L_α seems to be about moderate. It's kind of middle - it looks like around 2°/g. The effects of L_α and the pitch attitude response are noticeable. You can see it but they don't look to be particularly objectionable. There is a little sensitivity there but I've begun to think of this in an almost desirable nature. This is probably the limit of how much L_α effect you want in the pitch attitude response. I notice that when I'm making a heading change at the constant altitude. Actually this is a good airplane for that.

I find that I can maintain my altitude with fair precision by flying pitch attitude, thereby maintaining altitude and rate of climb fairly accurately so that my turns tended to be pretty level and I was pretty happy about them.

Usable bank angles - I would say are generally all bank angles.

I think perhaps the worst trouble I have with the configuration is trying to maintain a rate of climb or a rate of descent in level flight. I'm not really sure why I had so much trouble but it's certainly true with this configuration that you can't fly rate of climb. There apparently is too much lag between the g response and your command. To do this, you tend to oscillate if you try to fly rate of climb directly. I was quite successful in flying pitch attitude, cross checking with my rate of climb.

Is the airplane difficult to trim? No, I thought that it trimmed fairly easily. It's not the best nor is it the worst. It was fair - fairly good I should say.

Attitude control satisfactory? I'd say it's fair and not good. There is a tendency to oscillate and bobble the configuration, and therefore, I would call the attitude control only fair.

Normal acceleration control a problem? I'd say this is probably only fair also. You have a tendency to overshoot your g's.

Flight path control - I'd rate that as fair also. I thought that it was better in turning flight than in symmetrical flight.

The factors that entered into my selection of gear ratio - stick force per g, of course, in the turn, which tended to make me pick lighter forces. The accurate control of g and pitch attitude with a minimization of the tendency to overshoot the g - all these latter factors tended to make me pick heavier forces and I chose 120 as a compromise.

Can I hold altitude straight and level? Not as well, considering everything, as in turns. Actually, I can hold it and hold it fairly well. Climbing flight and descending flight with the wings level seemed for some reason to give me more trouble. Can I hold altitude in turns? Yes, fairly well. I'd say that that was fairly good.

Bank angle range that's usable? All bank angles.

Maintaining airspeed a problem? It does require cross checking. This is one of those configurations that requires some airspeed checks, but only intermittently and it doesn't get off very far. You just have to remember to add power when you're going to climb and descend or add a little when you're going to pull a lot of g. You don't have any trouble in that regard.

Special piloting technique required? No, I'd say the old-fashioned techniques worked the best, namely good attitude flying.

What instruments am I using most? The attitude indicator very definitely, cross checking acceleration and rate of climb. Less frequently - altitude, least frequently - angle of attack and airspeed.

Any instruments inadequate for this configuration? I don't think so.

Summing it up, I'd say that the worst characteristics of this configuration are the little tendency to oscillate. The g overshoots, and this leads to little imprecise flying. I was trying to decide all the way through whether to rate it a 3 or a 4. I thought that it was good enough in turns that it was satisfactory and that made it a 3. Yet generally flying it around, I thought that there was a little tendency to bobble. I had a little difficulty in flying a given rate of climb or rate of descent. That bothered me and tended to make it a 4. I think that I'll compromise and call it a 3.5. This is probably on the borderline between satisfactory and unsatisfactory. Configuration 20 is rated a 3.5 in smooth air.

PILOT C
CONFIGURATION 20, ROUGH AIR, 16 APRIL 1962

This is not a good configuration in rough air to start with, due to the tendency to bobble in pitch, and furthermore this is a configuration that responds quite a bit g-wise so the ride is poor. It did seem to me that maybe the somewhat low damping of the configuration in pitch may have caused the ride to be poorer than it might otherwise have been. In other words, for a lot of the time ... but first of all, the g seemed to be worse when I was flying it than just sitting here watching it open-loop. Furthermore, the level of the g's most of the time was moderately low. I don't really mean that, I mean moderate, say in the range of ±.5 g. Every once in a while you get a ±1 g oscillation. This seems to be too much. I believe that I always feel on shaky ground when I come to rate these things in rough air. As I look down the categories, I think that probably if this configuration could handle more

damping, it might have been a 6, but I can't call this acceptable for 30 minutes. I think that I'll rate it a 7 and say it's bad. I'd have a tough time flying it for 30 minutes. It seemed that I made it worse at leastto some extent by flying it. I didn't seem to make it worse in pitch attitude, but I made it worse certainly in g. Configuration 20, following the rough air, is a rating of 7.

PILOT C
CONFIGURATION 24, SMOOTH AIR,

This configuration is difficult to trim. Fact is, it's a difficult configuration to fly. I would say it's a very poor configuration for the generalized mission that we have. I think it's unacceptable. I just generally wander around. I can fly it. It's not unflyable. It's not even dangerous I don't think. I would suspect that on a very smooth day you can trim it up and land it all right. It requires a lot of throttle, but I think it would be possible.

In trimmed flight, your problems are getting the right airspeed and damping. Of course, it means that angle of attack has got to be right, rate of climb has got to be right. Those two things will change the power required. Angle of attack changes the drag. Drag changes the power required. Climbing or descent angle change the power required. So you're busy of the throttle constantly during this configuration.

Configuration has low L_α, very low in fact, something in excess of 15°/g.

Short period characteristics are fairly good, not good, but fairly good. Probably a period of, I don't know, probably a couple of seconds. Damping ratio approximately 30%, 35%, something like that.

I think I have adequate control of my g, just don't get very much g.

I think I have adequate control of my angle of attack. It overshoots a little bit, but I think it's adequate for this configuration. The response follows my inputs, I think, fairly rapidly. I'm not complaining in that regard.

The pitch angle response to elevator steps is oscillatory. It starts at a very high rate, stops, goes back. In other words, starts wandering in one direction and comes back a little bit, stops again, and then finally gets to going. It's not very satisfactory in that regard.

The biggest problem you have though is controlling flight path. It's a problem that you change the angle of attack in order to change the rate of climb and you've got to add power. You don't know exactly how much to add, but you add some if you remember. And then when you get to desired rate of climb you've got to reduce the angle of attack back to zero again if you're in 1 g flight or else back to the value if you're in a bank angle to hold flight path level. All the time your attitude display changes each time, and the pitch attitude for level flight is a large function of what bank angle you're at. Generally, it's like flying partial panel instruments in an ordinary airplane.

You can't really see your flight path. You're constantly hunting - by trial and error you are trying to control the flight path and make it go where you want to. Very imprecise control - don't like the configuration.

It's not what I like in the way of handling qualities. I can't fly it very well. It makes me think I'm either not a good pilot or else it's a lousy configuration, and I know it's a lousy configuration.

Bank angles - you can get up to 30° if you're doggone careful - any more than that is no bargain.

Altitude change - well, I can get up to 2000 ft/minute rate of climb up or down and get that established and the right power to hold the airspeed, then I can control the rate of climb pretty accurately by feeding in elevators as a function of rate of climb error. It goes real good. I tried the same thing about level flight and I should be even more successful, and I have the feeling I'm a little less successful. There again, I'm not only controlling rate of climb, I am inherently controlling altitude and maybe this has some influence on the degradation of my performance.

This configuration is really not too bad about level flight. One of the problems is you can hold the pitch attitude exactly level and if your power isn't exactly right, then you start sinking and you don't even know it from looking at pitch attitude. So all sorts of things can happen while you're tracking pitch attitude and you're not immediately aware of them happening and therefore you're quite late in taking corrective action. To the questions:

Airplane difficult to trim? Relative so.

Attitude control satisfactory? Not too bad.

Is my acceleration control a problem? The control isn't. The magnitudes that are available to you are certainly a problem.

This other question that I've been answering everytime - is flight path control satisfactory? The answer is absolutely not - damnably poor.

Factors entering into my selection of gear ratio? I would say it's a compromise between the forces required in a steady turn, namely stick force per g type of consideration, and the sensitivity of the attitude display to my control inputs. I think this is a pretty fair compromise here.

I'd like to know one thing. It seemed to me that my ailerons were less sensitive than they have been. I find this is to my likeing. This configuration is really better in regard to the roll rates you get due to aileron input.

Can I hold altitude? Not very well. It's a real problem. Flight path control in general is terrible. Straight and level, I can't hold altitude well unless I'm in a very tight closed-loop. Turns, I don't know, I have a great deal of difficulty. Once again, in a real tight closed-loop, all my instruments are really working at it, I can fly it level. It is relatively imprecise and if it starts to get away from me then it usually goes quite far. This configuration is one of those that you can very easily get into very high sink rates. In other words, a situation where your angle of attack is high, your airspeed is bleeding off, your flight path is going down and your logical inclination is to pull more g's and that makes things worse. What you have to do is roll the wings level and if you happen to be in a turn, get out of it, add power, and sit there and wait for the sink rate to stop. I don't like that.

What instruments do I use most? Well, attitude and angle of attack. This is the configuration I've been flying angle of attack a whole lot – rate of climb, airspeed – those four. Accelerometer is rather useless. I don't even use it. Altimeter – I use it, of course, but I find it's strictly a cross check instrument. I'm not too often there, because I usually know long before I've done anything about it that I've got a problem going down or going up, so I work on changing the flight path and am less concerned over the absolute altitude. Consequently, I do a lot more wandering in altitude.

Instruments inadequate for this configuration? I don't think so. I'd sure like to see a flight path display. I'd like to see more information on the attitude instrument. The fact that I have to cross check and assimilate all this information makes me more imprecise.

What will I rate this? I don't know. If I read the definitions, it's at least a bad. Aircraft controllable, but required major portion of pilot's attention. This one is stable and everything. It just requires a major portion of the pilot's attention to make it go where you're intending it to go. It's very lousy. I suppose it's a 7 or an 8. I could almost call it an 8. In other words, up and away flight I suppose is not too terrible, but if you think about holding altitude or something like that - maneuver with it - it's just impossible. It's unacceptable certainly. I'll rate it I think an 8. This is really not consistent with the word definitions. In terms of the word definitions, I think it would be a 7. But those word definitions better fit the situation of a nearly unstable vehicle. Although this is stable, it's flying like a rock. You're not able to do very much about its flight path, and it's not dangerous from the standpoint of losing control of it, but it's dangerous from the standpoint of your IFR. You might run into someone else. So maybe I'm rating this one too severe on this, but I'm going to call it an 8.

PILOT C
CONFIGURATION 25, SMOOTH AIR, 16 APRIL 1962

I don't like the configuration. It's a low L_α , moderate short period frequency, somewhat low short period damping.

I selected a gear ratio of 300. It was a compromise between the forces in a 60° banked turn, a 1 g turn, and the initial pitch attitude response to elevator inputs. I had to compromise my force preferences in terms of stick force per g in turns by making the gear ratio lower in order to get a satisfactory reduction in sensitivity to the pilot's initial inputs and pitch attitude.

Straight and level flight – well, it looked like the damping ratio, short period, was perhaps a little higher damping ratio than the last configuration, I believe - not much, but I'd say on the order of 35 - 40%.

The airplane is a little difficult to trim.

Attitude control satisfactory? No, I think the attitude control is poor. The reason is that when you put an elevator step in, the pitch rate stops and then actually reverses. The attitude decreases a little bit and then it proceeds on at a reduced rate from what you would expect from your initial response.

Normal acceleration control is a bit of a problem, not much, actually - I'll take that back. It's not too much of a problem because you have to pull so much angle of attack to get a g – it varies quite a bit with airspeed. I'm now on my correct airspeed. If I put a 1 g step in, it looks like about 7°. It takes about 6 or 7° angle of attack, probably, for an incremental g.

The effects of the L_α on the pitch attitude display, for example, are objectionable in this configuration due to the large sensitivity, tendency to bobble, and the fact that there is an elevator step and the pitch rate actually reverses.

Normal acceleration control I do not think is a problem. I misstated it earlier. There is a tendency to overshoot g. For example, I just had trouble trying to pull an incremental g. I always pull too much, so really I guess it is some problem but it's not a severe problem. It's mostly due to the low L_α and the fact that your pitch attitude display reflects your α responses as well as your steady state pitch rate response. Hence, you tend to slow down your inputs and you have less of a tendency to over-g it.

Flight path control I'd say is fair to poor. You have troubles maintaining level flight. They're not severe but this configuration makes you work harder.

The airspeed does change with everything you do. This makes you divert some of your attention that you would ordinarily devote to pitch attitude display over to the airspeed and the airspeed corrections (throttle corrections) that are required.

The factors that entered into the selection of the gear ratio I've already discussed.

Can I hold altitude? I'd say fairly well straight and level, fairly well in turns. During rolls, it's very difficult to hold altitude. This is one of the places where the side stick exhibits its undesirable characteristics, trying to make pitch corrections when you're executing a rolling maneuver.

Bank angle ranges that are usable? 60° maximum.

Is maintaining airspeed a problem? Yes, it requires considerable corrections. The airspeed changes while you're pulling g, requires a throttle correction.

Special piloting techniques required? No, I'd say the normal techniques of attitude flying work well with this configuration. There is a definite tendency to smooth your inputs with this configuration in order to keep from bobbling it.

What instruments are you using most? - attitude, airspeed, rate of climb, g, altitude, almost in that order. It seems that I look at the airspeed almost as much as the rate of climb. Maybe you should interchange the airspeed and the rate of climb - I should use attitude, rate of climb, airspeed, g, and altitude.

Are any of the instruments inadequate? No, I don't think they are. I notice that in the climbing and descending turns (climbs and descents more than in symmetrical flight, but also in turns) if you try to fly rate of climb, you oscillate the airplane, and if you tighten up your gain on your rate of climb in putting in elevator inputs as a function of the rate of climb error, you go unstable. There's a definite tendency to bobble this configuration. It leads to imprecise flying.

I've been trying to come up with a rating here. I'd consider this to be an acceptable and unsatisfactory airplane, somewhere in the vicinity of a 5 to 6 rating. I think that poor is the best word to describe the handling characteristics. It's actually on the kind of bad side of poor, but I think that I'll rate it a 5.

PILOT C
CONFIGURATION 25, ROUGH AIR, 16 APRIL 1962

From the standpoint of ride, this configuration was fairly good. Most of the g excursions are of the order of . 2 or . 3. In fact, mine are now around . 2 g.

However, the pitch attitude disturbances are quite large for the number of g's. So it makes you work to minimize pitch attitude.

Airspeed control seems to be no problem in this straight and level maneuver. I noticed that I could look around at the other instruments while I was tracking.

It seemed that I maintained my altitude to probably ±60 feet. I would say that that was pretty good for a configuration like this.

My initial inclination was to rate it a 6 just to show, not from a ride standpoint, but from an attitude standpoint, that the disturbances were objectionable. However, I don't really feel that that is quite accurate. Anyway I think that I'm going to rate it about a 5.5 just to show that the attitude disturbances were considerable.

The ride is pretty fair. When I think back on the previous configuration which I rated I believe a 7 in the rough air, the g excursions were up around 1. Then on the other configuration 20, there was, as I remember, large attitude disturbances there. Essentially it was a 7 on the basis of attitude and ride disturbances. You would not change this one at all due to ride. Ride is satisfactory. The attitude disturbances are sufficiently large that the constant bobbling and pitching might be quite objectionable. Perhaps I must downrate it some for that. If I downrate it to a 6, it was enough better than the last configuration. I didn't think that accurately described the difference, so I think I'll rate this configuration 25 a 5.5 in rough air.

PILOT C
CONFIGURATION 26, SMOOTH AIR, 19 APRIL 1962

This is a pretty good configuration. It has a few relatively minor things the matter with it in smooth air which I'll comment on, but basically, it's a pretty good configuration.

The speed is 420 knots and I selected 40 for a gear ratio. I selected a gear ratio on the basis that anything lighter I had difficulty controlling pitch attitude in a 60° bank. In other words, if we increase the gear ratio any higher than 40, I would start to have oscillations in controlling pitch attitude. And yet I had the feeling that the gear ratio of 40 gave me a slightly heavy forces in the 60° banked turn. I went down and tried a gear ratio of 20 and I felt the forces were too heavy, plus I didn't seem to have as good control there either. So I thought the 40 is a good gear ratio for this configuration.

I also had the feeling after flying it for a while that the forces are not too light. For one thing, the L_α is high enough in this configuration that you don't see your short period response very noticeably in your pitch attitude display. Hence you rely on your, in most cases, your peripheral vision of your g meter to tell you how much g you are actually

pulling and the force has to be heavy enough that you've got a pretty good feedback to yourself as to what you're putting in and calling for in the way of g's.

The airplane trims up fairly well. I didn't think that trim was any particular problem.

In straight and level flight the configuration exhibits a moderate stiffness. I would say the period is a little less than 2 seconds. The damping ratio is - well, the response is oscillatory. I can see easily 3 peaks following a pulse. Damping ratio is probably 30%, possibly 35%.

In response to elevator steps, there is very little pitch rate overshoot. There is some, but the pitch attitude display is relatively insensitive to my elevator controller. In other words there is not much pitch rate overshoot when you put an elevator step in. It does respond a little faster than it does in the steady state. The pitch rate you get is perhaps a little higher than the steady state, but not very much. You do notice a slight, very slight, hesitation. It doesn't seem to bother me at all. I would say it is a little objectionable from the standpoint that I just don't see my g response at all in my pitch attitude display, and I find that is somewhat objectionable when L_{α} is so large that I don't see it. I don't know whether my opinion would be the same in the air, but that is what it is here on the ground where I like to be able to depend on my pitch attitude display to tell me something about my short period response.

Heading changes at constant altitude went well, you have good control. You can fly level, you can make small corrections pretty well. I felt that I had good control of pitch attitude. I could maintain level flight quite well, both in 30° banked turns and 60° banked turns.

Short period response seems to be close enough coupled to your control inputs that you seem to have a good positive control of the configuration.

When you're trying to make altitude changes and trying to control rate of climb, you have pretty fair, pretty good, control of rate of climb. It seems to be close enough. The airplane seems to be close enough coupled and the elevator inputs that you can make small corrections. I find that it is still better to fly pitch attitude pretty tightly and cross check your rate of climb. However, if you do go over to your rate of climb, you tend to put in a little more elevator in response to rate of climb errors. I think you find that the thing is fairly controllable. You tend to oscillate about your desired rate of climb. You can stay fairly well within ±100 to 200 ft/min of, say, 2000 ft/min up or down.

I'd say that the attitude control is satisfactory and it's pretty good. My only objection is - well, I guess that doesn't refer to attitude control, but I was going to say that my only objection is that I don't see enough of my g response in my attitude display for good all-around control of flight path. But the attitude control is satisfactory.

Normal acceleration control is a bit of a problem. There is a tendency to overshoot your g a little bit, and you have to refer much more in this configuration to your g meter because your attitude display does not give you the sense of what you're putting in. Normal acceleration control is quite good, however, from the standpoint that it is pretty closely coupled to your inputs, and I like that.

Factors that enter into selection of gear ratio? I've already discussed that.

I can hold altitude, straight and level and in turns. I think I can do it pretty well.

I'd say that all bank angles are usable.

Airspeed is not a problem in this configuration. There is very little change in airspeed with pulling g's, so you don't have to cross-check airspeed very often. I did notice that when airspeed got off I had a pretty good sense of it from the fact that I could feel my trim changing. So you have another feedback there that tells you to go look at your airspeed.

Special piloting techniques required? No.

What instruments are you using most? Attitude and acceleration, and rate of climb. For maneuvering, I'd say attitude and accelerometer; for flying a steady flight condition, attitude and rate of climb. Of course you cross-check with your altimeter and of course heading, but I haven't been discussing that particularly. You do not use angle of attack and you very seldom have to cross-check with airspeed.

I would say that none of the instruments are inadequate for this configuration.

One final comment - you do have, at this speed, to fly attitude fairly closely. Small attitude changes produce a fair rate of climb and rates of descent, but the problem is much better at this speed than it is, for example, at 1800 knots.

As far as rating this configuration - it's acceptable, it's satisfactory. It's I think almost basically a good configuration. My only question in rating it, has been whether to rate it a 2 or 2.5, I'm not really sure which. My only criticisms of the configuration are the little tendency to overshoot the g (which isn't too critical apparently) and the somewhat lack of short period response in the attitude display. However, that is a relatively small objection here too. Everything goes pretty well. I'll rate it a 2.5. The main objection is the little oscillatory tendency I have with the accelerometer, with acceleration. I think this could be a little bit of a problem in certain kinds of flight operations. In instrument flying, it certainly is no problem at all. Extrapolating to the general mission, I would say that this is slightly objectionable and otherwise would have been a good - a 2 rating.

PILOT C
CONFIGURATION 26, ROUGH AIR, 19 APRIL 1962

This is a rating of 10. I've tried several times to get through 2 minutes of this noise, and the accelerations exceeded 4 g's. I would consider this unflyable for the 30 minutes of assumed rough air flying. If I may use a "fluke", a couple of times, but actually there are accelerations produced by the noise that are in the vicinity of 4 g's. The pilot has no opportunity to minimize those. My g's were oscillating probably ±1, when the system would go off. Actually the accelerometer in here was still responding up to 4 g when the system went off, and it had not even reached four g, so that indicated that it was a sharp-edged gust. That large a magnitude I consider to be unflyable. The other thing that was most noticeable on this configuration is that the pitch attitude disturbances were tremendous. I guess I must have gotten used to flying most of these because these attitude disturbances were similar to what I had done yesterday at 250 knots. I really expected to meet them in smaller attitude. I don't really have much more to say about the configuration, and that kind of makes it pretty bad when you can't even stop the g's from exceeding 4 in the rough air maneuver. I don't think you could stand 30 minutes of that.

PILOT C
CONFIGURATION 32, SMOOTH AIR, 2 APRIL 1962

I am not sure how valid my ratings of this configuration will be. I noticed that the short period damping was changing and I was told the reason. It was due to the fact that as the speed changes, L_α varies, but $M_q + M_{\dot{\alpha}}$ does not. So there is a change in damping with changes in speed, such that at the lower speed, my speed decreases from time. The damping gets worse. My speed increases above trim speed. My damping gets better, and since the damping is somewhat low anyway, the effects of these changes are fairly large.

I selected my elevator force gradients on the basis of the lower damping, so even that is not too valid. The unfortunate thing is that even though I say this here, sometimes this gets lost and the ratings are used sometimes without the comments and this does not get in there. So I don't know. I would say I picked a setting of 3 on the gear ratio, probably would have picked a 5 based on the dynamics at this particular speed (700 at the trim speed). But considering the fact that the damping did decrease with speed and it was lower damping that I was observing when I selected it - that is why I picked what I did, mostly because of the overshoot and the g response. That is the reason I selected the relatively low gear ratio as a protection against exceeding the structural limits of the vehicle due to the overshoot in normal acceleration due to pilot inputs. I don't like the airplane very well, and I am not sure how much I am prejudiced by these changes in damping with speed now, but I will do the best I can.

Trimming goes fairly well. It is not the easiest airplane to trim, but it is satisfactory in this regard. I am not really sure what my difficulties in trimming are due to. I just was not able to trim it as well as some of the others. In straight and level flight, I do not have too much difficulty in the configuration, except once again when the speed decreases, and I pulse the elevator and observe a response about trim airspeed.

I would say that the damping ratio is probably fairly good. I don't know how to guess the damping ratio. It is something like 30%, 25%. It is lower than the one this morning at

700 knots. That is one of the things I noticed.

I definitely have a tendency to over-g the configuration. I overshoot my g, and this I would say is my principal objection to the configuration.

As far as the pitch attitude display, I noticed that in response to elevator input, the nose initially starts a little more rapidly than the steady value, and I notice a little hesitation which apparently is due to the low short period damping rather than L_α because there is not very much of it And it is not objectionable, what I see in the pitch attitude display.

I would say the L_α here is pretty doggone large. I don't get angle of attack change as I pull g's, and I would say that all my problems come about here due to the low short period damping ratio. The stiffness of the short period is not too great either. I don't know, something like a 4 second period.

So I would summarize by saying that I have difficulties with the g overshoot that made me pick my gear ratio low, forces heavy. And I am definitely concerned with the structural limits of the airplane. Also, I am bothered somewhat by the fact that my damping is variable with the airspeed. I made descending turns, not too precise. Apparently the relatively low frequency in the short period gives me some trouble. Something does. I tend to hunt more than, for example, the configuration that I had this morning. I can't tend to hunt for my rate of climb, or my errors in flying rate of climb are considerable greater. Just generally, a less acceptable configuration - climbing and descending turns that applies to.

All bank angles are usable.

You can pull as much g as you want to. That is half the problem, you can pull too much.

Is it difficult to trim? A little, but not real difficult, but a little. Principally, I guess it is a little difficult because it takes a while for the g to settle down. Every time you make a little correction, you have to wait till the g settles down. It oscillates.

Attitude control is satisfactory - on the attitude display it is not too bad.

The acceleration control, though,is a real problem. I tended to overshoot my g's. And also I have to put an input in and wait a fair length of time before my g steadies down so I can see what a steady state value is.

As I said, the factors that entered into my selection of gear ratio - I'm principally concerned over the structural integrity of the vehicle due to the g overshoot.

Can you hold altitude straight and level? Fairly well. Turns? No, not too well. Once again, my control over the acceleration is not as good as I would like it. It is not too bad. It is not as good as I would like it. Consequently, my altitude gets away. I do much better by holding constant g and controlling flight path with bank angle.

Bank angle range usable? All bank angles.

Maintaining airspeed a problem? A little bit of one. I mean I have been hunting back and forth here. I think I am a lot more concerned with airspeed on this configuration for one thing because of the damping. I don't think the drag equation, for example, is causing any great difficulty in controlling my airspeed. I think I am just more aware of airspeed in this particular one.

Special piloting technique required? A lot of smoothing is certainly required. You have to be very conscious of your elevator inputs. You put one in smoothly and hold it for a while to see what you are going to get ultimately, and if it is not what you want, then you correct it smoothly. So a lot of smoothing is required on the pilot's control and that is the principal reason for selecting the low gear ratio.

What instruments are you using most? I planned on using the pitch attitude and the accelerometer, cross-checking with rate of climb and altimeter. I remember this morning the configuration I had, I did not pay as much attention to my g's because I could gauge pretty well what I was going to get from the force gradient. Here I have to watch my accelerometer pretty carefully.

Any instruments inadequate? I do not think so. Rate of climb is still as bad as it always

was. It is not particularly worse in this configuration. I would say my rate of climb is not adequate - it never is. The angle of attack meter may as well not be here. I can't detect my changes of angle of attack L_{α} is so large.

I don't know what to rate this. I get involved with this darned lack of mission here. It certainly is not in the first category. It is not acceptable and satisfactory. It is not unflyable. That eliminates those two. I think that it is probably acceptable satisfactory, but on either the poor or bad, and my inclination is a bad - I would say it is probable either a 6 or a 7. In the sense of dangerous, it is somewhat dangerous due to the tendency to over-g it. But once again, this is not so bad until you start losing airspeed, and I am trying to qualify all these comments on what I see right at 700 knots. This configuration is a puzzler. It is once again the problem the pilot talks about the lack of a well-defined mission. I would say for entry this is a 6. For a fighter it would be probably at least a 7 or an 8. So, in other words, I think it would be acceptable and unsatisfactory for re-entry type of mission where accurate maneuverability is not much of a concern. The fact is that it might even be as good as a prior to that. I will have to say 6, and then for a fighter, something like a 7 or 8. I don't know where to have to put it here. We are talking about going pretty fast here and so I think it should be a lousy vehicle. I don't think that I cam conceding that I am doing a dog fight, or something like that with it. I don't think that is realistic. So, there just comes the question as to what I do consider the mission of the vehicle to be. I am almost tempted to make it a 6.5 just to show that I don't know where to put it. I will rate this a 6 for generalized mission. I don't like it very well, but certainly the airspeed is right at 700 knots and the damping is as I see it. The period is long and objectionable. I will rate it a 6.

PILOT C
CONFIGURATION 32, ROUGH AIR, 2 APRIL 1962

Following random noise, unflyable. Every time we turn the random noise input system on. So even without the pilot in the loop, the g's are so large that they exceed +4. So I can't fly it. I can't stay on the system. And also, as a pilot, I don't think I could stand such a thing for a half-hour anyway. So I would say that this is unflyable for a half-hour. So this is a rating of 10 with the turbulence.

PILOT C
CONFIGURATION 32A, SMOOTH AIR, 3 APRIL 1962

This is a configuration which has very unusual characteristics, namely - you get elevator in a turn. Let's say when there is a bank angle, there is an elevator input. This I would say makes it an interesting configuration, and also gives me considerable problems.

The first thing - in trimming the airplane, I have some difficulty. The control precision right about level flight is not the very best.

I selected a gear ratio of 3. I started off with 10, that was too light. 5 felt about what I would like from the standpoint of steady state and stick forces, but there was a tendency to overshoot my g, and consequently I picked a little heavier force, and I think that this value of 3 is probably a pretty good compromise.

In straight and level flight trying to trim up, I would say that this is not the best of configurations, but it is no great problem, but it is not real good in this regard either. I find it fairly difficult to establish 1 g flight. I have a great deal of difficulty with the elevator trim control. Seems like I am going from one winding to another and neither winding is right - it is much, much too sensitive. I would like to have maybe 10° rotation correspond to the amount of the control, or let's say the amount of trim control that I use. In establishing straight and level flight here, I can't even detect the motion – it just feels like I'm bouncing from one winding to the next. So this is not very good. It makes it difficult to trim in itself, but outside of that the airplane still does not have the best of trim characteristics.

In straight and level flight it is noticeable that the damping ratio short period is a function of airspeed. I tried to hold the airspeed pretty accurately at 700 knots, and if I got off speed, I tried to discount the lower or higher damping which I would see. Short period looks like maybe 35, something like that - 30% - well let's say right about 700, I would say it is maybe 35% of critical, and consequently you get a noticeable overshoot when you put an elevator input in. The period is a little bit on the long side, so you have to sit there and wait for the oscillation to at least go through one cycle before you can begin to guess it,

what your steady state g's will be. This gives me some difficulty also and so it looked like; I haven't timed the period, but I will do it when I get back in trimmed flight, but something like 4 seconds, and this is getting a little long. I have to wait approximately 4 seconds after I put an input in to begin to guess at what the resulting g is that I am putting on the airplane. I don't think this is a very good situation for precise control.

When I make heading changes at constant altitude, I get in trouble. For 30° bank angles I have to hold forward pressure in the turn. This is a peculiar type airplane and I don't like this. But once again, I could learn to live with it, as far as flying it, if it didn't get worse. And so I go to a 60° banked turn, and surprisingly enough, it is almost right. In other words, it is very nearly trimmed at 2 g's in the 60° banked turn. That means that I don't have to put much corrective force in on the elevator if I just remember when I am going to roll into a 30° banked turn to command a little forward pressure. If I'm going to a 60° banked turn, don't do anything, and this works pretty well. This I could live with, but what I can't live with are two characteristics, or two resultant happenings, from this characteristic of elevator in a turn apparently due to pitch rate. The first thing is that if I roll rapidly from one bank to another, it is just like putting an elevator step in, and my g overshoots. So if I go from a 60° banked turn one way to 60° the other way, instead of pulling up to about 2 - 2.5 g's (like it would if I did it slowly) the g's would go up to 3.5 or more. Actually I shut the system off a couple of times. So if you overshoot your bank - well.... Then the other characteristic is that the more I increase my bank angle, the more g's I pull, so if I roll rapidly from level flight to a 60° bank and overshoot my bank angle a little bit, I also overshoot my g even if I don't put any elevator inputs in. This is no airplane for anybody. It is unacceptable without any question because of this characteristic.

I tried the altitude changes and they went not so well. It is once again this problem of holding a precise pitch attitude or g, establishing and holding a precise g in pitch attitude, 1 g in the case of a level climb and slight nose-up in pitch attitude. I just tend to oscillate at a relatively long period and very small attitude, just enough that it makes my accuracy very poor in holding a constant rate of climb.

Certainly the resolution of the pitch attitude display affects this. Undoubtedly short period characteristics affect this by their long response time and oscillatory nature.

But anyway the altitude changes with the wings level are not too bad. They are not good, but not too bad. So anyway, you come to

You come to the climbing and descending and this is not good either, because for climbing and descents, the turns I usually use are somewhere around 30° bank angle and this derned thing – I'm pushing forward on the stick. This doesn't lead to control precision. I just don't like the configuration. First of all, it is dangerous. I will go through the comment list:

It is somewhat difficult to trim, not too bad.

Attitude control is fairly satisfactory, but normal
Normal acceleration control is not very good due to the overshoot and also due to the long period - it takes so long for it to settle down. L_α is very large. I don't notice too much hesitation in the nose in the response to an elevator step. I think most of the hesitation that I see is just due to the overshoot g.

Factors that enter into my selection of gear ratio I have already discussed. Its effects on the damping ratio and the g overshoot tend to make me pick heavier type forces.

Can I hold altitude in straight and level flight? Fairly well. Turns, not very well at all, due in part to the basic short period characteristics and due to even much more in the turn than the requirement of having to hold varying amounts of stick pressure to maintain my altitude.

Bank angle range usable - not more than 60°, and that is because of the g's that you get in a turn.

Maintaining airspeed a problem? Not too bad, no. I don't think this is one of the problems of this configuration. However, I may be paying a little more attention to it with this configuration because I can see the damping change as the airspeed changes.

What instruments am I using most? Pitch attitude and normal acceleration very definitely, cross-checking with the rate of climb and altimeter. The angle of attack meter is useless.

I can't even see it. That is an exaggeration, but it hardly moves for 1 incremental g.

Are any of the instruments inadequate for this configuration? The pitch attitude display for all of these configurations on speed in a little insensitive, in other words, a detectable change in pitch attitude causes a real large change in rate of climb.

Rating of the configuration? I'm going to call it a 9, dangerous describes it. In fact, I was tempted to call it a 10, and maybe I should, but because the mission is so ill-defined, I think I will call it a 9. By that I mean that it is absolutely unacceptable for this generalized mission. Just like some airplanes should have g limiters, this should have a bank angle limiter, and the banking should absolutely be limited to 60°. If it had this, then the acceptability would perhaps move up to maybe a 7. I still wouldn't like it. I think it would still be unacceptable, but it would not be dangerous then and probably something like a 7 would describe it.

PILOT C
CONFIGURATION 32A, ROUGH AIR, 3 APRIL 1962

I'm not even going to bother looking at the random noise. It shuts the system off it is so large. The configuration is a rating of 10 in the presence of noise and the presence of turbulence. A pilot could not possibly stand a half an hour of this, and particularly with these handling characteristics, but I doubt if he could standit just from a physiological standpoint, and the configuration is rated a 10.

PILOT C
CONFIGURATION 33, SMOOTH AIR, 3 APRIL 1962

This is quite a good configuration thus far. I think my over-all impression is that the best thing I can say for it is the rapid correspondance between what I put in and what I get out. In other words, I don't have to wait a while after I put an elevator input in to see what change it's going to make in my response. The changes are ultimately rapid.

The short period damping appears to be good. The stiffness is high.

The speed of the response is quick. The L_α isn't what we'd call low, it's lower than what I'd think of in terms of the normal T-33. I'd say that it takes 4 or 5° to pull an angle of attack to pull 1 g. This is about twice the normal time lag. This doesn't make any difference. The only thing that I notice that I have any difficulties with in the configuration is that there may be a trace of low L_α .

I do tend to want to fly pitch attitude very tighly. I was trying to maintain within a quarter of a bar width pitch attitude accuracy. I'm trying to make changes in pitch attitude so that indication like when I'm going from a turn, a climb to a descent, I'm trying to establish a new rate of climb and a new rate of descent. I tend to bobble the airplane a little bit. There are very small amplitudes, but there is a tendency to bobble it when tracking pitch attitude very closely. The other thing I notice is when I make a sudden pull-up, the nose initially starts about twice as fast as it ends up moving. It comes to a halt and then proceeds on. The pitch attitude response looks like it starts at about twice its steady state rate, comes to a halt, and then proceeds on with its steady state rate. I can detect this, but it doesn't seem to bother me directly anyway.

The ability to trim is very good. This configuration is one of the best to trim that I've had. The trim path, elevator trim sensitivity, is what I would call right just the opposite of the configuration that I had this morning which the trim sensitivity was much too great. The level flight small disturbance seems real good, no problems.

As I had noted in the elevator step, the responses do hesitate and actually just about come to a stop. There is a detectable difference in the initial response and the final response. This doesn't seem to be giving me any direct trouble, although it may be the cause of my tendency to bobble the airplane - it may be contributing to it. I'd rather fly pitch attitude very closely.

In making specific altitude changes, it's the best configuration that I've flown so far. I can control my rate of climb much more accurately here than in any configuration that I've seen thus far. I'd call this a good, positive rate of climb considering the problems that I had just due to the inherent speed of the airplane (mainly that the pitch attitude display is relatively insensitive) that's what I mean by that comment. Climbing and descending turns

are the same way. I'm able to control my rate of climb during these much better than any configuration that I've flown, that I can remember anyway. Everything seems quite natural and well suited to my personal dynamics. The only objection is my tendency to bobble when I try to control pitch attitude too closely. I'll run through the comments:

Is airplane difficult to trim? No, it's easy to trim.

Is attitude control satisfactory? Yes, it is quite good except for the slight tendency to bobble when I try to make corrective attitude changes of small magnitude.

Is normal acceleration control a problem? Definitely not.

Factors which entered into my selection of elevator gear ratio? Possibly the rapid initial response may have entered into it a little bit, but basically I picked it on being able to resolve my elevator inputs accurately. I almost picked a gear ratio of 300, but settled on one of 225. I almost picked 300 because the steady forces were quite comfortable and easy to hold.

I don't like a 60° banked turn. I found that I didn't have the resolution capability that I desired in terms of my elevator inputs. As you all know, the side controller in pitch has definite breakout forces. I thought that I had to pick my force gradient a little bit heavier so that I could resolve my inputs properly. With this force gradient, I imagine that some people might term it a little heavy, but I like it because of the fact that I can put in accurately what I want. I'm still able, within my strength capabilities, to pull 6 and 7 g's.

Can I hold altitude? Yes sir, very well, straight and level and in turns.

What bank angle ranges? All bank angles are usable.

Maintaining airspeed a problem? Not particularly, no more than any other configuration, perhaps a lot less than some.

Special piloting technique required? I can't detect any special techniques that I'm using. I find that it's a pretty straight maneuver-type airplane. One of the things that I guess I should note is that with a somewhat low L_α when I roll into a turn, I have to consciously increase my pitch attitude for level flight. That is detectable on the horizon indicator.

What instruments do I use the most? I'd say almost entirely pitch attitude and rate of climb, cross-checking with the altimeter. In other words, I've got a pretty good correspondence here. I fly essentially pitch attitude, cross-checking with my rate of climb. The accelerometer I use also in the turns. I'd say it's a normal type scan pattern – angle of attack a little bit because of the fact that it's moving and I can detect this and look at it occasionally.

Any instruments inadequate for this configuration? I'd say no.

It's certainly acceptable and it's certainly satisfactory. It's a good to excellent configuration. I'd say that it had excellent longitudinal handling qualities. I wouldn't call it optimum because of this tendency to bobble it. I wouldn't call it optimum because of this hesitation I notice when I put an elevator step in. There is the difference, because my initial response and final response which is slightly objectionable. I wouldn't term it optimal. I still think the lateral-directional damping is too low. I wouldn't therefore term this an excellent airplane. I'd have to downrate it. I think that I would tend to call this a 1.5 – good to excellent type airplane and not rate it a 1 because of the lateral-directional characteristics and because of the slight tendency to bobble it.

PILOT C
CONFIGURATION 33, ROUGH AIR, 3 APRIL 1962

This is a real good configuration. It doesn't respond very much to the rough air. I didn't seem to have any real control problems. I did notice one thing. For small amounts of control input, the side controller is somewhat objectionable. The up inputs fit in fairly well but the down inputs seem like the breakout force is more in the down direction. I think in general, this side controller leaves a lot to be desired in the down inputs. It's a good configuration and better than I expected it to be. I guess I did expect it to be fairly good in rough air. The turbulence doesn't cause much disturbance. I'm able to control altitude and rate of climb fairly accurately. I think that I deviated probably as much as 100 feet, no more. I don't think that I'd rate it a 1. I still have objections to the lateral-directional

characteristics. Certainly my opinion of it is very high. I can see that there may be some slight difficulty here due to L_α and my controllability - due to the somewhat low L_α . The effect this has on the turbulence is certainly good so this may be a real fine type of compromise configuration. In other words, if you made L_α bigger, you'll probably get rid of this little tendency to bobble. Maybe, I don't know whether you would or not. It would be at the sacrifice of this desirable flight through turbulence. This may very well be a very fine type configuration. I certainly have no qualms about rating it a 1.5. Here in the simulator it seems to be an excellent type configuration. The ride was excellent in the way that I didn't notice g's. When you compare that to where I was pulling 4, 5, 6 g's in the configuration I had this morning open-loop, there's just no comparison I guess. This is a very fine configuration from the ride standpoint.

PILOT C
CONFIGURATION 34, SMOOTH AIR, 6 APRIL 1962

What we have here is a very low L_α configuration. We have a well damped short period and apparently a very stiff short period. It's not certainly overly fast responding, but it is fast to respond, stiff and well damped. In other words, it gets there plenty quickly but doesn't overshoot. I think that the short period characteristics save this configuration from being worse than it is. And I have to decide how bad it is and I haven't yet. Let's start by saying that it's very definitely not acceptable and satisfactory. Then I find that I can do nothing real well with this configuration. I had trouble with everything. I can't do anything real well. It's strictly a stick and throttle airplane. You've got to watch your airspeed a lot. When you increase the angle of attack and climb, you have to have throttle, and if you decrease the angle of attack and are descending, you may have to take it off. You just have to have lots of feedback on the airspeed.

This brings up a point. I would very much like to have a dial which tells me how much throttle I've got in. I think that I haven't mentioned this before because on most configurations I don't use the throttle much. The reference mark is down here but I think you can learn a little more rapidly to fly these configurations if you had an instrument on the instrument panel that told you what your throttle position was, or what your thrust was, or something like that to use back in throttle position. Something to show you how much you're adding without looking down and bring it back to the same position that you started with. You can also move it back to a position that you've already found to hold airspeed in a, say, 45° banked turn.

You can trim the airplane. That's not one of its worse features. In level flight you can trim it all right.

In straight and level flight with small disturbances, the short period is moderately stiff, well damped. In other words, its response time is respectively short considering the very high amount of damping. The damping - I can detect no overshoot to step inputs. I would therefore judge the damping ratio was in the vicinity of unity. The L_α is very low. This means my elevator steps - well, really what happens is that you've got a pretty good separation between your α response and your $\dot{\theta}$ response. I'm probably confusing the issue here. We're down at 700 knots and your L_α is low enough that you don't - I didn't pull over 1 incremental g since I've had the configuration and that takes in the order of 15° of angle of attack so you can see that I'm not going to maneuver in excess of 1 g. Therefore, my bank angles are restricted to certainly under 60°, and when I get into 60° banks, I never know what's going to happen. There are times when I end up with full throttle, trimmed in one incremental g, definitely 60° bank angle, and my flight path pointed down and it continues to go down for one heck of a long time. My airspeed doesn't build up so you're on the back side of the power curve apparently, and that's not a very good place to be. You shallow out and take some of the excess angle of attack off and you get some excess thrust and you can accelerate as soon as the gets better. I don't like the configuration for over 45° of bank.

When I put an elevator step in, the first thing that happens is that the pitch angle reflects my α change. In other words, basically what I see in the pitch angle response is the α response because it's big. Then the nose starts very rapidly and moves along with the g's. It stops and the g's stop. It just comes to a halt. Then it continues on at a constant rate, a very low rate as compared to the rate that it moved in the α response. This is discomboobera ting.

I picked 400 for my gear ratio. I couldn't make it - well, I didn't fool around too long.

I wouldn't want it much more sensitive than that because of the initial pitch attitude response to control inputs, and I wouldn't want it much heavier than that because the stick force per g is so high. It's a kind of a compromise - a hurried sort of thing.

The next thing, I just generally have trouble holding altitude. I can't analyze it in this short a time and tell you all my troubles, but basically I had trouble holding altitude. What I like best is to fly rate of climb like on some of these other configurations.

I think that my biggest trouble comes when I'm making large changes in my flight path at a certain condition, say level flight. You ask me to maintain level flight and track bank angle and rate of climb really accurately. I can do a real good turn then. I have to cross-check on my airspeed and adjust throttle accordingly. However, if I'm in a descending flight path and you ask me to pull up to a climbing turn, I'm almost lost. I can do it, but I have to do it very gradually and please don't hurry me because it's just going to use up a lot of airspace.

I don't have much g to maneuver with. I've got lots of trouble handling the drag changes, but I'm correcting for them with my power and then I'll miss or overshoot by what I'm trying to do just because it's all rather ponderous and I'll have to change the attitude closely and I'll have to go back. If I go from pulling a .5 g positive to pulling a .5 g negative incremental, my pitch attitude is going all over the place because I'm pulling 7° or so angle of attack each way and changing 15° in my pitch attitude in the initial response to my inputs.

It's not a good configuration. However, it is flyable. I don't know what to call it. I'm kind of lost here. What mission - I don't know. The saving grace with this configuration is, I think with any other short period characteristics it would be quite unacceptable. I'm tempted to call it a 6 or a 7, which means that I don't know whether to put it at the bottom of the acceptable and unsatisfactory or at the top of the unacceptable. The only reason I'd put it at the top of the unacceptable is because of the short period characteristics. I've got good correspondence between elevator inputs and g, no overshoots. I can be sure that when I put a step elevator in, my angle of attack will come in and not overshoot. This is good. I think that I'll rate it a 6. I don't like it very well. I'm just indicating that the short period characteristics make it good enough to rate it a 6 or 7. Let me think just a second - it's a 6 rating.

PILOT C
CONFIGURATION 34, ROUGH AIR, 6 APRIL 1962

Through random noise or turbulence, it doesn't respond g-wise to the air disturbances. The disturbances in pitch attitude I'd say were a couple of degrees at the most. I'm able to fly them. If you don't do anything about them, it doesn't make much difference except it changes your altitude a little bit. The fact that you have a pretty low L_α (which I've noticed before with other low L_α configurations) actually amplifies your pitch response to high frequency disturbances in pitch. It allows you to correct them without doing much - before much can happen to your flight path. So actually, I thought that it was pretty fine in this regard. I'm going to rate it a 6. I'm not going to change it. The turbulence was fine. All the objections that I can see in this configuration are entirely due to L_α.

PILOT C
CONFIGURATION 35, SMOOTH AIR, 30 MARCH 1962

Trim is difficult, not from the standpoint of airspeed, but just trying to find out where level flight is. Pitch attitude is unrelated enough to the flight path angle that I had problems in establishing what zero flight path angle is. Rate of climb - there isn't enough instrument, at least as presented, to give me enough information. The fact is, I would say, my major complaint against this configuration all the way through is that I don't know where zero flight path angle is. Rather, I just can't find my flight path angle. I found that using angle of attack or g, either one, helps me quite a bit. Angle of attack is better because it's more sensitive. The principal difficulty, as I said, I had was with finding out where my flight path angle is since my pitch angle is unrelated to my flight path angle.

Now, this undoubtedly is a low L_α, relatively low anyway, configuration. The g response is slow but adequate. It's adequately fast for the rest of the handling characteristics. That isn't what's bothering me. What's bothering me is the pitch overshoot. There's some g overshoot as in the last configuration. There was a little in that one and in this one there seems to be a little more, but once again, that doesn't seem to bother me. I can control angle of attack and g really precisely. There's noticeable overshoot, but it isn't too bothersome.

My main problem is trying to control pitch attitude. When I put an elevator step in, the attitude starts real fast and is very, very loose in pitch response. By that I mean that it responded very rapidly to my initial elevator inputs. Maybe we can take care of that except for the fact that then it stops and it actually will reverse. The pitch rate will reverse attitude most. It actually reaches a maximum, then decreases, and starts in the original direction again. It just takes a long time to steady down to a steady pitch rate. It's this looseness or high initial response compared to the steady state response of pitch attitude that gives me a lot of trouble. In fact, this happens very suddenly and the angle of attack changes moderately slowly. I realize as an engineer that the sum of the two angles - the difference really - is my flight path angle. I mean I can't add these two things up - they're different phases and everything else. But with normal airplanes, you tend to use pitch angle as a measure of flight path angle. When the nose is pointed up, you assume you're going up or pretty quickly will be. In this configuration, that is definitely not the case.

It was a real problem to select a steady stick force because I had to compromise between the initial pitch response, the stick force per initial pitch response, and the stick force per steady pitch rate or steady normal acceleration. It's a compromise and what I ended up with is too heavy for the stick force per g; the stick force per steady state pitch rate is too heavy; but the stick force per initial pitch acceleration is too durned light. Since it's a compromise, I don't know whether I ended up with the right compromise. It's not a very good configuration.

I had definite problems with the rate of climb. I need something to tell me whether I'm going up or down better than this rate of climb. It doesn't satisfy my needs. In other words, it would be interesting to display flight path angle here. I think I could do a better job if flight path angle were displayed to me. It might be interesting to try it with some of these configurations.

As far as trimming the airplane goes, it was more difficult, mostly because I can't find where my flight path is. I keep saying that, but this is a problem. It's like flying partial panel as compared to flying full panel on instruments. Full panel on instruments, you've got your attitude displayed to you directly and for normal airplanes, your flight path is in effect displayed to you directly. Partial panel instrument flying, you have to integrate the readings of a lot of instruments and then deduce where you are attitude-wise. This is an analogous situation and it's pretty difficult to be precise. So I don't like it. I don't think that it's very good. It's controllable.

And now I come to the biggest problem of all - how do I rate it? First, let me go through the answer to your questions.

I can use up to 60° bank angle.

It requires large power additions in order to keep from dropping off at airspeed. That's no problem because we have enough power here to handle it.

The heading changes of the constant altitude are darn difficult. It's not that the heading changes are difficult, but it's that constant altitude bit. Specific altitude changes are difficult. You tend to overshoot or undershoot. You just don't know where your flight path is. Climbing and descending turns - all my turns are climbing and descending. I can't fly level and that's my problem.

The airplane is moderately difficult to trim. I'd say even fairly difficult to trim. I don't mean to trim airspeed-wise, I mean to find a given flight path, namely, level is difficult.

Attitude control is not satisfactory for the aforementioned reasons.

Normal acceleration is not a problem. There is a tendency to overshoot. If you watch the accelerometer by itself in the elevator steps, you'll notice an overshoot. What happens is - in your normal maneuvering, due to this large pitch attitude overshoot, you tend to put in your inputs very slowly, and hence your actual closed-loop g response is better damped. It's also slower, which is somewhat objectionable.

Elevator gear ratio as I said was a compromise between the initial pitch response sensitivity. Actually, for some of those forces that I examined, the lighter ones had a tendency to go unstable here. The only way that I can stabilize this configuration closed-loop is to accept a much heavier stick force per g than I would like based on the steady state g.

I can't hold altitude very well. I can get to straight and level flight. If you get to straight and level flight, and then start to make very tiny corrections, you can hold altitude fairly well. In maneuvering flight, you can't do this.

Up to 60° bank angle can be used. That means that you're pulling in the vicinity of 15° angle of attack which is about all you want to do.

Maintaining airspeed is a problem. It takes enough angle of attack to maneuver that I have to add power. If I forget to add power, then my airspeed drops off. However, I have plenty of power so it doesn't seem to be a real great problem. It's just that if you want to fly precisely, it is a problem.

Special piloting technique? Yes, you tend to smooth your inputs an awful lot. First of all, the heavier forces tend to smooth and you tend to do things fairly slowly so you don't excite this pitch thing; that makes your g's come on slowly. It's not a very maneuverable sort of vehicle. I wish I could figure out a piloting technique to give me what my flight path angle is. If I could, then I would say that I would use this special technique.

The instruments that I'm using most are attitude, angle of attack, not g very much (I don't pull enough g to much worry about), and rate of climb; cross-checking with altimeter and airspeed.

Are any instruments inadequate for this configuration? Yes. I don't have one that will give me flight path angle. The ones I got as a set are not enough.

Then I come to the problem of rating this configuration and I don't really know how to. I know that this is the other pilot's problem – in defining the task. When I say it's acceptable or unacceptable, then I have to say for what. It's certainly unsatisfactory. Let's put it this way - it is not satisfatory for anybody's task that I can think of in the generalized sense. I think that it is also not acceptable for most tasks. I wouldn't want these handling characteristics, I don't think. If some prime augmentation system failed and I had to get home, I think that you wouldn't have any trouble with this. It's not really dangerous but you can't fly precisely. I wouldn't want it for re-entry. I couldn't hold my angle of attack well and my nose is constantly bobbing any time that I put anything in in the way of an elevator input. Unacceptable - yeah, I think this is unacceptable. Dangerous? It depends on the mission. For some missions, it would be dangerous, but I will not classify it as dangerous. We have other definitions here - aircraft control movability, minimum cockpit duties - that doesn't describe it. Bad aircraft control movement requires a major portion of the pilot's attention - that describes it. We'll call it a 7.

PILOT C
CONFIGURATION 35, ROUGH AIR, 30 MARCH 1962

The configuration is pretty inert as regards turbulence. I can hardly see the accelerometer move, so I didn't use the accelerometer. I flew the pitch attitude entirely, cross-checking with rate of climb and altimeter. I occasionally used my angle of attack, but I didn't fly it prime. Around trim, flight is pretty fair. It was easily disturbed. It was like something restrained in pitch by a rubber band. In other words, it doesn't have much damping. It feels like it's very lightly damped in pitch and so you kind of sit there and oscillate and you try to keep its mean deviations small. If you're a little low on altitude, you try to keep the rate of climb average. The rate of climb doesn't oscillate too much. If it does at all, its at a much lower frequency. You keep the nose pointed just a little above the horizon just a little bit as it's oscillating. The altimeter when high makes you keep the nose a little low. It's kind of an averaging process that's going on. The disturbances are small, but your preciseness to control is very lousy. I don't like it; I won't change my rating on it. It's certainly a good rough air type airplane from the standpoint of ride. From the standpoint of control precision, it's not very good. I stick with my 7 rating as before.

PILOT C
CONFIGURATION 37, SMOOTH AIR, 9 APRIL 1962

This is an interesting one. It is a configuration that apparently I am able to do less well with than I would have anticipated, just based on its open-loop response.

I selected a gear ratio of 25 and I believe I goofed on this one. I tried 50 to start with, that was too light. I went to 25, that seemed about right. Then I thought I'd better check it at 12.5 just to get it too heavy and I found that really wasn't too bad. It was too heavy, but I

sure had what appeared to be a little better prediction of what I was going to ultimately get. In other words, I could sense my outputs better. I went back to 25, then I tried 20, and then I finally chose 25, mostly because forces in a 60° banked turn were enough heavier at 20 that I felt I would get a little bit tired holding them for a long time. The particular short period characteristics we have here are such as to make the airplane maneuverable, so it is likely the pilot would be holding a 2 g turn for a long period of time. Therefore, I thought I should weigh that – some configurations have very low L_{α} . You wouldn't hold a 2 g turn because it would be 15° angle of attack and you couldn't stand the drag rise. So then you can pick any of your forces with them because you wouldn't have to hold them so long, or you wouldn't actually have to use that heavy force.

Well, what I see here is a configuration that is apparently between .7 and critically damped. I would like to say low frequency, because I don't really see frequency. The time delay between what I put in and what I get seems a little long. I think I prefer the shorter time delay. And I judge this on the basis, not of the numbers that I hear, because the numbers I can say 1000. I would think this

I would think this would be a fairly good configuration, but I seem to get into some difficulty here when I am trying to fly my rate of climb in the manner in which I was able to fly some of the other configurations. This configuration has a very high L_{α} . I don't normally detect angle of attack changes for the amount of g's that I pull in these maneuvers. Speed control is not problem at all. I set the throttle and generally leave it fixed, and occasionally make a slight adjustment.

Ability to trim is very good - I had no problems; straight and level flight, small disturbances, I thought the configuration was good.

There's no tendencyto oscillate the airplane due to g overshoot or anything like that, but there is a tendency to oscillate it in trying to achieve zero rate of climb in a turn. Generally turns with this configuration are less good than other configurations that I have seen. I can't use rate of climb as a primary input with the degree of precision that I have been able to achieve with other configurations, and therefore I have to kind of mark this one down strictly on the basis of its closed-loop flying characteristics.

It appears to feel as if there were – that I wasn't closely enough connected to my g response. And yet if I look at the number of seconds (measure the time delay between what I put in and when I get my g) it is what you would think would be a normal good type value. So all I can say is that it leads to problems. They are serious ones, but they are deficiences from an optimum airplane for sure.

The heading changes went all right. The altitude deviations were not great, but then once again, I really didn't feel I quite had the altitude control I would like, and part of this is traceable to the controller.

I found difficulty putting in small inputs. I can blame the controller and it may be the short period characteristics or I can blame the short period and it may be the controller, but I think both are tied up into it because, for example, if I put in up-elevator and slowly release, my g will stabilize at about 1.5, something like that. If I put in negative controller and release, the g will stay at about .8. So I don't have perfect centering here.

This may be the story - maybe that I have selected too light a stick force and consequently don't have the precision of changing my g. I don't really think this is the case because I try it. In selecting these forces I found I can change my g's by ±.2 easily around 2 g's. I felt that this was all that was necessary. So that is enough of that.

Climbing and descending turns – they were all right.

The attitude control seemed to be precise.

The rate of climb control in turns was poor – was fair. Here are the questions;

Airplane difficult to trim? No.

Attitude control satisfactory? Yes.

Normal acceleration control a problem? No, but I have to add another question. Flight path control in terms of rate of climb? Not as precise as I would like it to be or that I would expect of this configuration. It is not as good as I would expect.

I can't hold altitude very well. I can get to straight and level flight. If you get to straight and level flight, and then start to make very tiny corrections, you can hold altitude fairly well. In maneuvering flight, you can't do this.

Up to 60° bank angle can be used. That means that you're pulling in the vicinity of 15° angle of attack which is about all you want to do.

Maintaining airspeed is a problem. It takes enough angle of attack to maneuver that I have to add power. If I forget to add power, then my airspeed drops off. However, I have plenty of power so it doesn't seem to be a real great problem. It's just that if you want to fly precisely, it is a problem.

Special piloting technique? Yes, you tend to smooth your inputs an awful lot. First of all, the heavier forces tend to smooth and you tend to do things fairly slowly so you don't excite this pitch thing; that makes your g's come on slowly. It's not a very maneuverable sort of vehicle. I wish I could figure out a piloting technique to give me what my flight path angle is. If I could, then I would say that I would use this special technique.

The instruments that I'm using most are attitude, angle of attack, not g very much (I don't pull enough g to much worry about), and rate of climb; cross-checking with altimeter and airspeed.

Are any instruments inadequate for this configuration? Yes. I don't have one that will give me flight path angle. The ones I got as a set are not enough.

Then I come to the problem of rating this configuration and I don't really know how to. I know that this is the other pilot's problem – in defining the task. When I say it's acceptable or unacceptable, then I have to say for what. It's certainly unsatisfactory. Let's put it this way - it is not satisfatory for anybody's task that I can think of in the generalized sense. I think that it is also not acceptable for most tasks. I wouldn't want these handling characteristics, I don't think. If some prime augmentation system failed and I had to get home, I think that you wouldn't have any trouble with this. It's not really dangerous but you can't fly precisely. I wouldn't want it for re-entry. I couldn't hold my angle of attack well and my nose is constantly bobbing any time that I put anything in in the way of an elevator input. Unacceptable - yeah, I think this is unacceptable. Dangerous? It depends on the mission. For some missions, it would be dangerous, but I will not classify it as dangerous. We have other definitions here - aircraft control movability, minimum cockpit duties - that doesn't describe it. Bad aircraft control movement requires a major portion of the pilot's attention - that describes it. We'll call it a 7.

PILOT C
CONFIGURATION 35, ROUGH AIR, 30 MARCH 1962

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PILOT C
CONFIGURATION 37, SMOOTH AIR, 9 APRIL 1962

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Factors that entered into my selection of gear ratio? I think I have discussed completely.

Can you hold altitude straight and level? in turns? Not as well as I would like to, but certainly quite satisfactory for what I assume the mission to be.

The bank angle range usable? All bank angles.

Maintaining airspeed a problem? Absolutely not.

Special piloting technique required? No, and in fact, the ones that I have developed in flying rate of climb don't work as well.

Are any of the instruments inadequate? I find the angle of attack is rather useless, but I don't feel that any of the instruments are inadequate.

Now I come down to rating the configuration in smooth air. I find that this is a rather hard one to decide on. terms of g control and attitude control, I feel that it is a 2. In terms of rate of climb control, my positive feeling that I have control of where this airplane is going is a little lower than a 2. I have been de ating as to whether to make it a 3 or a 2, or half-way in between. I don't honestly know. If I decide on a 3, I kind of feel that this is being a little tough on the configuration. I certainly wouldn't want to make it any worse than a 3. I just had one more brief look at the configuration and I will rate it a 2.5. I will say my principal objection is difficulty in pinning down my rate of climb, which I find is somewhat necessary in the speed regime where we are flying where attitude control is not a very precise way of flight path control. In other words, the resolution requirements on my attitude gyro are such that I can't maintain my rate of climb as accurately as I would like to by reference attitude. Therefore I must use rate of climb as a more primary instrument and hence I don't have quite as good precision as I would like. So I think I will rate it a 2.5. I don't like to quite make it a 3 because it seems to be better in all the other respects than a 3.

PILOT C
CONFIGURATION 37, ROUGH AIR, 9 APRIL 1962

The controllability in the random noise or the turbulence was very good – I thought it was excellent. I had absolutely no difficulty in putting in what I wanted to put in, and I was tracking attitude and cross-checking with rate of climb and altitude. The g's were just going – it was not a primary instrument at all. So there was absolutely detrimental in the way the configuration responded to the random noise as regards the controllability standpoint.

All my adverse comments are based on ride and just the shaking you would get; that was substantial. The accelerations went probably as high as 1.5 incremental, both positive and negative. This is a pretty good rattling. Once again I confess that I don't know how bad this would be for 30 minutes. But I think I would stake my own money to the effect it would be pretty ridiculous. I would be so beat around that I don't think I would be much good for anything at the end of 30 minutes. I would certainly – at the best, this is acceptable and unsatisfactory, and at the worst just slightly unacceptable. I think that the word bad probably describes the ride characteristics – bad, probably even very bad, but I don't rate it that far into the unacceptable category to call it a name. I don't think I would possibly call it as high as a 5 just because the g's would be just too heavy to take for 30 minutes, I think. So I'm left with a 6 or a 7 – kinda on the fence. I hate to penalize it too severely because it was so controllable. I think the fact that it was so controllable would make it a 6. Any oscillation tendencies, things like that, I would probably rate it a 7 based on the ride. So I think I will make it a 6 for the random noise or turbulence maneuver. The degradation in opinion is apparently due to the responsiveness to turbulence n terms of the g's that are on the airplane. I think they are too high. This is bad to sustain for 30 minutes. I think this is as bad as could be acceptable. So that is why I called it a 6. I would rate it a 7 if the attitude control had not been so good. The attitude control was good, consequently, I think a rating of 6 is in order.

PILOT C
CONFIGURATION 38, SMOOTH AIR, 30 MARCH 1962

I have completed the trim in straight and level flight. A few disturbances were found throughout the whole flight. I want to talk about that for a minute. Basically, it's a good airplane. I think that I ended up with a setting of about 30 on the elevator gear ratio. The trimmability of the airplane is good. I had no real problems with it. It responds to throttle

and elevator well. The maneuvers involving disturbances about level flight - basically the dynamics are good.

However, I do have a tendency - it has a certain looseness on the initial response to pilot inputs. I would just venture to guess that this is a somewhat low L_α for these short period dynamics. I'd say that, based on the fact that when I pull steady g's rather abruptly and I put an elevator step in, I detected a nose response initially quite rapid. The pitch attitude response is initially quite rapid and then it stops. The pitch rate actually appears to go to zero and th it progresses on at an orderly rate. It's this stopping of the relatively rapid initial response compared to its final steady response that I am noticing. Also, that's what I called the "looseness". The other thing that I'm noticing is somewhat objectionable. This is the tendency of the pitch rate to go to zero in the process of responding to an elevator step. This makes my pitch control a little less precise than I would prefer. Otherwise, I would say that this is a pretty good configuration.

The lateral-directional characteristics are approximately those of the normal T-33. Dutch roll is somewhat lightly damped. The rudder pedals are somewhat relatively sensitive. There's not much motion of the rudder pedals in order to get some sideslip, but basically, the forces are pretty good although a little on the sensitive side. The roll responses are certainly good and the roll forces a little on the light side. It's certainly a fighter-type roll control. It could be a little less responsive and still be quite satisfactory. However, this is not so responsive that I find it objectionable. It is what I would call good and light.

I've now done the rest of the maneuvers including the altitude changes and climbing and descending turns, and also the heading changes, maintaining constant altitude and usable bank angles. For heading changes it was a pretty good configuration. I can slowly roll into a turn, go into 60° banked turns, pull my 2 g's absolute, and hold it pretty well. I varied my rate of climb with bank angle and I had no problem at all. Understand that I was not changing my g's and it's only when I change my g's that I have trouble with this looseness in pitch.

The usable bank angles go all the way up to - well, they're all usable.

I pulled 4 g's once and went off the system. There is a lot of g available in this configuration.

I had adequate throttle to keep the airspeed relatively constant. I don't seem to have too much trouble with that.

In making specific altitude changes, I found that it was pretty difficult to set up a rate of climb. Being specific, when I hold it, principally because it was such a small attitude change that I was not able to hold it very precisely. Consequently, any small errors in ability to hold the attitude caused large changes in the rate of climb. So I did have trouble making a constant rate of climb ascent. Climbing and descending turns are certainly all right from an attitude task standpoint, except once again I still have difficulty in setting up and maintaining any specific rate of descent. But I was willing to take whatever I got from a given attitude. This was fine, but I found that I got large variations in my rate of climb.

Is the airplane difficult to trim? No.

Is the attitude control satisfactory? It is satisfactory, but it's less than desirable.

Is normal acceleration control a problem? No, it is not.

What factors entered into your selection of an elevator gear ratio? Mostly I picked it probably from doing 60° banked turns. That was pulling 1 g, 1 incremental g, when it feels comfortable.

Can you hold altitude? Yes. Straight and level? yes; turns? yes.

What bank angle range is usable? All bank angles.

Is maintaining airspeed a problem? No , it is not.

Is there a special piloting technique required? No, there isn't.

What instruments are you using most? I find that I'm using attitude and acceleration the most; cross-checking rate of climb, airspeed, and altimeter.

Are any of the instruments inadequate for this configuration? I don't know that the instruments are inadequate. I would like a better indication - let me say that in order for me to

set up and maintain a given rate of climb and descent, I need a better instrument tha attitude indicator. I don't know what it is. I need a better instrument than the rate of climb. I'm tending to set up an attitude and cross-check with the rate of climb and make changes in my attitude indicator, but this is not satisfactory.

So then I will have to rate this configuration. This is a kind of general rating. Over-all I didn't have too great problems with the configuration. I've noticed that it was a little loose in pitch in the sense that I got a relatively large initial pitch acceleration when you put in a sudden input as compared to the steady state. The pitch rate that you got for that input, for example in an elevator step, a sudden pull-up, the nose responded initially rapidly and then stopped and then came on again. The g response showed a little overshooting. It is not enough to particularly bother me. The overshoot in pitch rate seems to be much more sizeable. I can pull all the g I want, no problems there. I think that I would categorize this as an acceptable and satisfactory configuration. Howeve r, I would only call it fair due to its characteristics in pitch and also, it's not the best of directional characteristics and the aileron forces are relatively low. I would say that if I had no problems in pitch, this could probably be as g- ɔd as a 2 or 2+, maybe even as low as a 1- configuration; I don't know. We'll see as we go along. True speed only seemed to give me a problem in the factors of rate of climb. To hold a precise rate of climb was somewhat difficult. My rating is 3. I don't think that the characteristics in pitch are objectionable enough to rate it a 4, although it's getting close. I might have called it a 3.5, but I'm trying to stay away from a .5 rating if at all possible. I've categorized this as satisfactory, not the best, but satisfactory. It's a rating of 3.

PILOT C
CONFIGURATION 38, ROUGH AIR, 30 MARCH 1962

This configuration is very good in turbulence. I have noted very little response. The ability to control deviations that you saw was quite good. I didn't try to control the high frequency g's that I saw. I just tried to maintain a pitch attitude which would give me on the average, a level flight. I started the configuration indicating about 24,750 feet and I tried to maintain that altitude. I didn't climb up to 25,000 and I probably deviated about 100 feet down and 50 feet up, or something like that. It really is a pretty good configuration. The g response was low. The turbulence didn't make any problems at all flying this in rough air. I'd still rate this a 3 for the same reasons as before. I'm rating it over-all. I was favorably impressed by its rough air performance. It possibly even proves somewhat in my mind that with this rough air performance, I would be less inclined to rate it a 3.5 which I had considered before. Therefore, it's a good solid 3.

PILOT C
CONFIGURATION 43, SMOOTH AIR, 2 APRIL 1962

This is a good configuration. The lateral-direction
the Dutch roll is not well enough damped for a good airplane. The ailerons are a little on the sensitive side, particularly it seems that around a 60° bank angle, I tend to oscillate just a little bit. In other words, the oscillation tends to come from the fact that I cannot put in a small enough input to make a small change in bank angles without overshooting.

The short period damping ratio is something like 35%, and this makes a noticeable overshoot in g responses and hence I picked a little bit heavier forces because of this overshoot. I felt that it was necessary to do it because of this tendency to overshoot the g. I have a very good awareness of the acceleration I'm calling for and so I think the setting at 8 is quite comfortable, and I think I am relatively happy with it. It is a little on the heavy side I admit.

The airplane is very easy to trim.

The L_α appears quite high and that means that it takes very small angle of attack to maneuver. I notice this is the sense that the drag terms are not large because my airspeed does not vary much in maneuvering flight. I have not bothered to use the throttle at all, and as long as I stay about trim altitude even though I pull g's, I don't appear to lose this significant amount of airspeed.

In straight and level flight, the airplane is easy to trim up and I have no problems with it.

In pitch when I disturb the airplane, there is a noticeable overshoot in the g response. This is slightly troublesome, but not overly objectionable. It would become objectionable in our

precise tracking task.

In flying, I am making heading changes at constant altitude. I have very good success with the configuration. I can pull and hold 2 g's very accurately and maintain level flight by just making small bank angle changes of 5° on either side of 60 and control my flight path angle that way. This is where I had my principal difficulty, though, in trying to achieve those 5° changes of bank angle. By the time I get an input in when I am holding the g, I tend to put in – I get a little more roll rate than I desire and I overshoot the desired bank angle correction. So there is probably something to be desired there. But it is certainly a good configuration.

When I try to pull g's in symmetrical flight, I notice that for step elevator inputs, the nose responds initially somewhat more rapidly than it does in the steady state and then it slows down, doesn't quite come to a stop though (I cannot notice the difference in pitch rate) and then proceeds on in an orderly rate while I am holding the g. So there is a little bit of either L_{α} or short period damping ratio effect in the steady pitch rate response. It is not objectionably large; the forces are good.

I have not made any specific altitude changes or climbing or descending turns. I will do that now. We took the three recorded maneuvers – the pulse, the step, and the throttle step. And now I have just done the altitude changes and the climbing and descending turns. I find that in general it is a very good attitude tracking airplane. I find that it is not the best in rate of climb tracking though. In other words, I had difficulties holding the given rate of climb. I found that it put severe requirements on my pitch attitude tracking in order to stabilize and hold my rate of climb at a given value.

Fortunately, there was a good correspondence betwenn my pitch angle and flight path angle; and hence I could fly a very accurate pitch angle and be sure that my flight path angle was kind of following in step. But even so, I found that 2000 ft/min up and down climb rates was equivalent to the width of the bar on the horizon. In other words, one bar width high and one bar width low was 2000 feet up, 2000 feet down. This meant that if you were going to hold your rate of climb to 20% above or below, which would be 400 feet above and below 2,000 feet per minute. This meant that you would have to hold your pitch attitude at a fifth of a bar width. This is beyond the capabilities of the equipment, I think, or very near the capabilities of the equipment in resolving what is going on. It is also asking an awful lot of the pilot to track that closely. In other words, he has to steer very carefully. In other words, an expanded scale would help. But it is a problem that comes with the speed. I think what you do is just set up an attitude and take whatever rate of climb and variations in rate of climb that you will get. In other words, the pilot will not worry too much about the fact that he is not necessarily flying constant rate of climb. Otherwise, it's a good configuration.

I would rate it 2 before the random noise maneuver. I would consider it both acceptable and satisfactory, and I would call it a good airplane. I would rate it below a 1 principally because the Dutch roll damping is not what I would call adequate for an excellent airplane. The other criticism is that the short period damping appears tobe a little low. In other words, there is g overshoot that I do not like. I think that if you took the g overshoot away, I would make it a 1.5. I will reserve that one for an airplane with a good Dutch roll damping. Also, the roll characteristics leave a little bit to be desired in the 60° banked turn.

Is the airplane difficult to trim? No, in fact, it is easy to trim.

Is attitude control satisfactory? Yes, it is.

Is normal acceleration control a problem? It's a slight problem. The overshoot g due to elevator inputs is noticeable and not overly objectionable, but somewhat objectionable.

What factors entered into your selection of elevator gear ratio? I have discussed that.

Can you hold altitude in straight and level and in turns? Very well.

What bank angle range is usable? All bank angles.

Is maintaining airspeed a problem? No.

Is special pilot technique required? No.

What instruments are you using most? I think the attitude and rate of climb, and of course the altimeter (attitude, cross checking with rate of climb and altimeter).

Are any instruments inadequate for this configuration? I would say no, except that for holding constant rate of climb the resolution required in pitch attitude, I believe, exceeds the capabilities of the pilot in viewing this attitude instrument. I do not know; I'm not suggesting anything to get out of this; I am just saying that the attitude holding requirements in order to maintain constant rate of climb are pretty tremendous.

PILOT C
CONFIGURATION 43, ROUGH AIR, 2 APRIL 1962

I can see that I have a real problem here. I have a real good airplane in smooth air, and a miserable airplane in rough air. The g range, both with me flying and then the open-loop, seemed to be ±1 - 1.5 g's incremental. And occasionally it would get up to +2 g's incremental. This is pretty miserable. I would hate to be beat around for 30 minutes like that. So I would say it is a problem. It was a good airplane, but you sure do not want to fly it down low. So I feel that I have to go all the way from acceptable and satisfactory rating of 2 in smooth air down to the unacceptable for 30 minutes in rough air. Now I think I can fly it, so I won't call in unflyable, but boy, for me to guess how unflyable this would be, is a problem. I know the few times that I have tried to look at the normal accelerometer in an ordinary airplane when I was riding in rough air, if I saw fluctuations up to ±.5 g, it meant that it was a very uncomfortable ride and I was just inherently concerned for the structural integrity of the airplane. Here I am seeing three times that much. I am sure I would be concerned for the structural integrity of me. I would be afraid, in controlling the airplane, if I was flying down low (which I presumably would be) that what was required of me to maneuver the airplane to avoid the terrain, or what have you, would cause me to force the oscillation at times. So, I would become concerned really seriously about the structural limits of the airplane as well as the structural limits of me. I think we might make it through that, but I would say if I had a rating here – a rating scale is not very acceptable for this, the definitions anyway are not very acceptable for the effects of turbulence. Maybe we should think about redefining the words as to apply to turbulence. In other words, I look at a 9 and it says dangerous. I agree that this is a dangerous configuration, but the words "aircraft just controllable with complete attention", do not describe this, because open-loop – I pull less g's than I do closed-loop. And so, only slightly different, but still perhaps a little less, and consequently the words do not describe this very well. I think I am going to settle for an 8. I may be generous there – very bad. I guess that I am really saying that it is flyable, but it is unacceptable and I am picking right in the middle of the category because this is the first one I have tried to evaluate like this. And I really do not know where to put it. So I will have to call it an 8.

PILOT C
CONFIGURATION 45, SMOOTH AIR, 9 APRIL 1962

This one is a little improvement on the last one. If I look at the short period dynamics, well, I don't know. I had the feeling there was a change, and yet if I say 1001, it seems like about the same time delay between my input and the response. And also, the damping is – there is no overshoot anyway – the damping is good. So if this configuration is stiffer, it is possible that this configuration is stiffer and more damping, for example, contribute to some of the slight improvement I have in flying this or handling this configuration. Or it is possible that the short period is the same and the improvement is due to the little bit lower L_α than the last configuration, I don't know. My roll is not to decide, but there is a noticeable difference. I have a feeling that even the short period is different, but I look and see on the accelerometer about the same time delay and there is no overshoot. So on that basis I would think that the short periods were the same. So I don't really know whether – the only obvious thing is that L_α is lower. The other obvious thing is that I have a little easier time flying this configuration. L_α is not so low as to make the θ or $\dot{\theta}$ response objectionable, that is still good.

By the way, I don't think I commented at all on the pitch rate or the pitch rate response to elevator steps when I discussed the last configuration, configuration 37. There was no noticeable overshoot in that configuration in pitch rate. It just looked like when you put the elevator on, the nose started to move at a constant rate and kept going.

Now for this configuration, you could have, for all practical purposes, the same situation. In other words, I can see that the nose does in actuality start what appears to be a little more rapidly here and it may actually overshoot just a little bit in pitch. But for all practical purposes when I put an input in here, the nose gets going and keeps moving. And in actuality I can't notice that it gets going a little faster than it ultimately ends up, but this

is hardly discernible. So I would say the attitude response is good here. Something has improved – I find that flying rate of climb is easier and it seems almost as if there is less effective delay between what I put in and what I get. Now I see you have changed the rate of climb. I put in the corrective input into the controller, and seems that I can grab that rate of climb just a little bit faster than the last configuration, and consequently I feel I have a little better control – more positive control of this configuration. Now this may be gear ratio factor effect but I'm not so sure that it is. By the way, I selected 75 as a gear ratio for this configuration

Now this configuration is very easy to trim – flying in that regard. Straight and level flight is excellent. Small pilot initiated disturbances about level flight - I thought it was excellent. Response is good and it is not oscillatory. There is no tendency to overshoot.

The pitch rate response is quite manageable and predictable. The pitch attitude response, of course, is the same.

When to heading changes at constant altitude, I had a little bit of trouble with altitude control. I realize that all pilots have some difficulty with this regard, but it seems that I have had some configurations where my altitude control was perhaps a little better, but this one is a definite improvement on the last configuration, configuration 37. OK, heading changes at constant altitude - the altitude control was better, but I don't think it was optimum. For specific altitude changes, that went pretty well. I had fairly good control of rate of climb. I have had better on other configurations, but this was certainly good. It was not excellent. Climbing and descending turns good, not excellent as far as rate of climb control.

So the lateral-directional characteristics I haven't particularly commented on. They appear to be those we have called normal before. They lack enough damping for me to really feel that I have a "1" airplane, certainly there is very little sideslip disturbance due to use of the ailerons and so the pilot is not overly concerned with what his Dutch roll characteristics are in smooth air. I'll run through the comments.

Airplane difficult to trim? No, quite easy.

Attitude control satisfactory? Yes, I would call it good to excellent.

Normal acceleration a problem? No, I would call it probably excellent and I would say that flight path control would be good.

What factors entered into your selection of gear ratio? I'm not sure what really did. This particular value felt good. I tried 50; it felt a little heavy. I tried 100; it felt a little too light. I tried 75; it felt pretty good. So it is 75. I felt I could resolve my inputs a little better with this configuration than I could with the last. I had a little more positive control of what my g's were. If I have the same short period characteristics, then I've selected a little better gear ratio maybe. Actually as I look, as I am doing right now, the resolution in terms of g – you know, I pull up on the controller and release it slowly and it stabilizes at 1.1. I push down on the controller and release it slowly and it stabilizes at .8. It is about the same as the last one. So maybe this configuration isn't actually any stiffer. Then perhaps all the difficulty – or all the improvement that I note is just due to L_α and I think perhaps more improvement can come about in the rate of climb and altitude control by having the short period perhaps a little faster.

Can I hold altitude? I would say that was fair to good, about good, I guess – good minus, both in straight and level and in turns. It is better than the last configuration.

More bank angle range is usable – all bank angles.

Maintaining airspeed a problem? A little more of a problem than the last configuration. I forgot to mention this. It is quite noticeable that you start to see angle of attack changes in maneuvering on the angle of attack meter, but you can also expect to see airspeed changes on the airspeed indicator and that was the case with this configuration. L_α is still pretty high, but low enough that I start to have to check my speed.

What instruments am I using the most? Attitude, rate of climb, accelerometer, cross-check with the altimeter. In other words, this is a configuration where you tend to use all of them except angle of attack.

Special piloting technique required? No, I don't think so.

Are any instruments inadequate for this configuration? No, I don't think so. This is a pretty straightforward type of configuration.

I think I'd just rate it a 2. It is a good configuration; in smooth air, I will rate it a 2.

PILOT C
CONFIGURATION 45, ROUGH AIR, 9 APRIL 1962

I find that this configuration is about twice as good as the last one in rough air. In other words, the g's I got during the ride were just about half of what I saw before. You have half of the L_α here that you had on the last configuration. That doesn't particularly concern me, what the value of L_α was, because the main things I notice is that it doesn't change my pitch attitude response adversely anyway. It is a noticeable change. I can detect it, but it is still just as good if not a little better. I think it is.

It smooths the ride very considerably. And I would say that my only problem now is how to evaluate this ride. I'm sure I am being inconsistent in my ride evaluations. I would say that this turbulence that I say here was about like perhaps what we had in that real rough ride in the T-bird coming back from California - coming up one of those passes. And all I can say is that was a pretty rough ride and I wouldn't have like to have flown it for 30 minutes very well. I mean I could have, therefore I would have to say immediately that it was acceptable. I would prefer something less than that.

Well, first of all, my controllability with this configuration was very excellent. Just like the last configuration, it was excellent. And I don't think I could detect significant difference between the two and the random noise maneuver; they are both good.

So once again, the change in rating is entirely due to the ride that I observed and what I think it would be like to fly thing in rough air in flight. Not in the sense of attitude control, but in the sense of what the acceleration would be doing to me for 30 minutes. So I think I called it a 6, but anyway, this is significantly better than that. I wouldn't term this poor, I don't think. It is fair, so it is going to he either a 3 or a 4 and I am not sure where to put it. It is unsatisfactory in the sense that this would be unsatisfactory for 30 minutes. I don't know, I think I will rate it a 4. I would like to explain that. I think it is just a little too rough a ride. It it is possible to get rid of this thing and that is the definition of acceptable and unsatisfactory. It is an objectionable characteristic - one objectionable enough that you point it out as being unsatisfactory for the mission. You would like to have have it fixed, but you can accomplish the mission if it isn't fixed. I may even be rating it too high, but I am trying to be consistent and with the degradation of the last configuration, I thought it was at the limit - just as bad as you could make it - probably should have 6.5, but as bad as you could make it from a ride standpoint and still feel that the mission could be accomplished. This one is I think definitely better than that - but still objectionable. So I think a rating of 4 would describe it fairly accurately and so I will assign that rating to configuration 45 following the turbulence.

PILOT C
CONFIGURATION 50 SMOOTH AIR, 6 APRIL 1962

Basically it's a pretty good configuration. I had a little trouble selecting a gear ratio. The first one I got, which was a setting of 40, was pretty good. I tried double that because I thought, if anything, that it was a little on the heavy side. I kind of liked that except that I found (now that was 80) I couldn't resolve my g's well enough. The breakout forces on the side controller were not too large in terms of the g introduced, so I tried 60. I thought that 60 would be a pretty good compromise. You know, the forces were enough lighter than 40 that it kind of satisfied me that way. Still I had trouble resolving the g and I over-g'd again today on this configuration about three times. Ken was getting a little tired of balancing it up so I went back to 40. Even at 40, I over-g'd it once, but I was fooling around so that isn't very significant. The forces are a little heavy. I still think that I would like less breakout forces or probably more important than that, I'd like more motion for my given force on the side controller. This particular amount of motion - when I get my motion big enough so that I like it, my forces are too heavy. This is principally a problem of resolving your g's - making small changes in g's, but precisely. With the breakout force characteristics that we have and the particular force gradient we have on the side controller, if the gear ratio is too large in number (depends on which way you look at it) well, anyway, if the gear ratio is too sensitive and the number is too large, this means that you just can't resolve your normal acceleration. You can't resolve small changes in it.

Straight and level flight trimmed up real decently, no problem for small disturbances.

It seems as though it's a moderately stiff short period. I don't know what the frequency is, I'd say that it's moderate; moderately stiff. In other words, my g's are fairly close behind my inputs. It's not what I'd call a high frequency. It's a moderate frequency type. Damping is a little too low. Once again, I can't say 35 or 40%. I'm either consistently wrong in regard to the damping ratio on many of these things. I noticed that there was a noticeable overshoot and I did worry a little about that. It's likely that my forces tend to make me a little heavier because I want better resolution of what I'm putting in. But generally I'd say that the short period characteristics are satisfactory.

L_α is quite large. I pulled one incremental g. I can't even see the angle of attack g. If it's anything, it's a .5°. So I anticipate already in this that we're going to have a rough ride in turbulence. In smooth air, it's a good configuration. I've put elevator steps in and it initially responds. If I look very carefully, it stops and then it goes on. I had the maximum range that was produced initially. So that looks pretty good in other words. I have to look closely to notice that it stops or almost stops. The final pitch rate that I get is not grossly different from the initial pitch rate and the maximum initial pitch rate, so everything looks pretty good. I didn't have too much of a problem.

Due to the speed that we're flying at, I had a little bit of difficulty in maintaining my rate of climb. I couldn't do it with pitch attitude. I found that, for example, I was using up to 2000 feet a minute up and 2000 feet a minute down and I can maintain that f ly well by cross-checking quite closely (you're flying quite closely) my rate of climb display and keeping track of my attitude as often as necessary keep it the way I wanted it to be. I use the normal accelerometer an awful lot in this configuration.

I got good correspondence between my elevator control and g. It seems to do very well and even though it overshoots, it's a predictable sort of thing. I seem to be able to get used to it. All in all, I'd say that the attitude control is satisfactory and so was acceleration control.

I've discussed the factors that entered into my selection of the gear ratio.

I can hold altitude by roughly positioning the nose and then flying the rate of climb very closely. I did the best job in turns by flying rate of climb, either flying level or in constant climb or descent in a turn.

Was maintaining airspeed a problem? Absolutely not. I didn't touch the throttle through the whole thing except to do my throttle steps. In fact, I gave up looking at it because it never changed enough. The changes in airspeed that I got were always proportional to the changes in altitude above and below 25,000 feet. There was a good correspondence between my altitude and airspeed, so I just balanced.

What instruments am I using most? Pitch attitude, rate of climb and accelerometer all about equally, considering all the maneuvers. Angle of attack, not at all; altimeter is the cross-check instrument, airspeed very seldom.

Any instruments inadequate? Pitch attitude isn't adequate for holding level flight. It's kind of hard to make precise rate of climb changes; rate of climb, I'd like to have a larger range.

I can't get very excited about this configuration. Short period damping is a little low. I'd categorize it as acceptable and certainly satisfactory, so it definitely is not a 1. I don't class it as excellent. I don't know why, maybe I'm not the type to classify anything as excellent today. The roll characteristics are such that not to disturb the Dutch roll, but in general the Dutch roll is too lightly damped for me to class it as a 1 airplane. It certainly would have to be the best - it would have to be a 1.5 at least with these characteristics. I think that a 3 would be unfair to the configuration because I think that it's better than that. Fair does not describe it adequately. All the things that I don't like about it are so small that none of them weigh heavily in my rating. It's just a kind of over-all feeling that I just don't like it as well as a 1.5 but I didn't dislike it as poorly as a 3. I think that the only thing I could call it legitimately is a 2 or a 2.5. I believe that I'd call it a 2 mostly because the normal acceleration overshoot is bothersome and outside of the inherent things due to the true speed, that's probably my principal objection to the configuration. Another objection is this side controller forces. I kind of feel they're a little bit heavy and the resolution isn't the best on the side controller so I think that I'll stick with the 2.

PILOT C
CONFIGURATION 50, ROUGH AIR, 6 APRIL 1962

The first thing that I was shocked by was this high L_{α} . The g response was not great. Through most of my maneuvering, I didn't see much more than a degree of two of α on the angle of attack meter during the smooth air maneuver so I figured that with such a high L_{α} configuration, the noise would be unacceptable on the instrument. It is not. However, it does respond quite a lot. I'd say that it responds at one incremental g enough to be quite disconcerting. Hence, I view riding in this thing for an hour or half hour as something that I'd just as soon not do. I am not well alibrated in this regard so I'm trying to be consistent in relating what I see. There's a relative comparison between configurations. I'm absolutely embarrassed to maybe be quite poor. Once again, I do feel that this is certainly not a very satisfactory ride with this sort of a turbulence response. If somebody tells me, OK, this is the best that you can do, well that's a horse of another color. I'll say: "You give me some pills that will hold me all in one piece for a half an hour and I'll try it and we'll see what happens". But I certainly couldn't look forward to it based on pas experience that I've had looking at accelerometers and relating them to what I feel in the cockpit. All that I can say is that turbulence which often reaches ±1 g is a pretty rough ride. It apparently is not going to break the airplane up, so that is one major consideration. If I say it going over 1 g very much, I would certainly consider it unacceptable. In my criterion here, if it's less than .5 most of the time, then it's probably satisfactory. It it's .5 to 1, depending on the handling characteristics at least from a ride standpoint, it's unsatisfactory. It it's bigger than 1, it's unacceptable, and if it's much bigger than 1 it gets unflyable, and flying it for 30 minutes is a long time. I really am only deciding here between rating it a 5 or a 6. Every once in a while it goes to 1.5 incremental. I don't know, I'm not well calibrated in this random turbulence. The controllability is certainly all right. What really happens, if I fly pitch attitude, is that I can't hack these high frequencies in the acceleration response. I mean that I can't minimize them, so what I do is fly pitch attitude and try to minimize the disturbances in the rate of climb and therefore in altitude. This level of turbulence doesn't produce much attitude change. I'd say that the biggest high frequency attitude changes that I get are, oh, 3/4 of the bar on the horizon indicator. So here we are, and we have to rate it; it's a 5 or 6. I don't know what. Every once in a while I decide that it's a 6. However, due to its controllability, I'd rate it a 5. I say that if I emphasize ride, it's a 6; if I emphasize controllability, it's a 5. I don't know - half an hour is a long time - 5.5 I can't make up my mind and I'm not going to sit here all night.

As I sit here reflecting and reading my rating scale, I think that perhaps I was a little bit generous on that (the smooth air rating). I think that I was influenced by - as a matter of fact, there wasn't anything real wrong with it and I still think it was better than a fair airplane but I'm not so sure that I wasn't a half a rating too generous and I say that principally because of the g overshoots. I'm finding that I'm leaning quite heavily - I won't change it. I'll leave it at 2, but I'd like to note that I think I'm weighting my ratings towards perhaps the re-entry mission where precise tracking tasks are less of a requirement of a mission. What I was thinking was that for a fighter that my rating was too good. It is not adequate for my concept of a fighter. I think that it would drop down to a 3 for a fighter, but I'm considering the fact that you're talking about a cruise type of mission, a general type mission where I can't emphasize one area more than another and I don't want to penalize the configuration based on one specific area. This is a bit of a problem. Maybe I'd better compromise here and call it a 2.5, but I'll leave it stand as a 2 since I have that while I was flying it.

PILOT C
CONFIGURATION 54, SMOOTH AIR, 5 APRIL 1962

The airspeed is 1100 knots. Actually, it wasn't too difficult to trim. The records went all right. About the straight and level flight it's a pe uliar configuration. The short period responses are relatively fast, little bit oscillatory. I'd say damping ratio is perhaps 35 - 40%. In other words, I can see 3 half cycles following a pulse.

The problem is apparently L_{α} is fairly low and it takes on the order of 9 - 10° angle of attack to pull g in symmetrical flight. This doesn't particularly bother me by itself, in the sense that g response is really not too bad. It is fairly closely coupled to your elevator controller and although slightly oscillatory, is not oscillatory enough to give you any apparent problems.

The problem comes in climb and pitch attitude. Initial response to elevator inputs is very

fast, very abrupt. Initial response is very large compared to the final response. I'm not good at measuring these things, but I'd say that to all appearances, the initial pitch rate or maximum pitch rate looks like about 3 times this steady pitch rate. This in itself makes the configuration somewhat difficult to fly. You put elevator input in and notice the response very abruptly. You expect that you're putting way too much input in, but actually if you wait until it settles down (which is perhaps a couple of seconds) the nose will go on at the right pitch rate and you check with your g's and you' e got the g's you desire. So the low L_α is apparently a problem in the precise control and in maneuvering flight.

There are other problems with this low L_α and that is that in steady maneuvers there's a steady and relatively large difference between pitch angle and flight path angle. And the difference between pitch angle and flight path angle isn't enough of a function of the g's you're pulling. In other words, if you're in 1 g flight, you'd have attitude indicator all set up so that zero pitch angle is zero flight path angle of the flight in other words. Then for example, you're in a dive or making your pullout, pulling 1 incremental g. You actually have to, in this configuration, ur nose to 10° above the horizon before your flight path angle gets to zero and then if you want to stay in level flight - you have to push the nose back down to zero indicated pitch angle. Now this is not too bad when you're thinking about it, but if you are performing as a closed-loop controller and in somewhat automatic fashion, this leads to some difficulty.

So special techniques are required; namely, that you are aware that this s going on and you adjust your control techniques accordingly. However, I'm afraid that f you got into a situation which required very close closed-loop and rapid control that you'd have a tendency to ignore these. Special techniques that you'd revert to your standard transfer functions and I think this configuration would give you trouble in oscillatory pitch standpoint.

I've been maintaining altitude in level turns, it's a problem. I mean that maintaining altitude in level turns is a problem and in both shallow bank angles and in steep bank angles. I tried two different techniques fo holding level flight in 60° banked turns. I tried to adjust my rate of climb by holding constant g and changing bank angle and I also tried holding constant bank angle and varying my g's to control rate of climh. I found that the latter procedure was more effective in this configuration. However it did mean that I had to cross-check very rapidly between g's and rate of climb. In fact I found that it was unsatisfactory. In fact, the open loop for period of response time for the short period went by because – if I noticed an error in my rate of climb, I would put in a carefully correct elevator input and wait to see what adjustment that made in my rate of climb. Essentially I worked between the controller and the rate of climb instrument and found that this worked fairly well. You were oscillatory, but small amplitudes, rates of climb, and in the ground simulator, this works quite well. In flight where you are getting oscillating g's while this is going on, I'm not sure that this is a good technique.

Altitude changes - I felt they went pretty well by once again applying the rates of climb very, very carefully; modulating my corrective elevator inputs as a function of errors and rate of climb; and maintaining quite tight, precise control. I do find that the rate of climb being located separately from the attitude instrument does present problems in that I have to share my attention and this makes it a little difficult and makes the maneuver more imprecise. As far as specific altitude changes, it went quite well. I think this is principally due to the relatively short time delay between elevator input and g response. I think this configuration is good in that regard and this allows me to fly rate of climb rather tightly.

Climbing and descending turns - I had similar problems with them as I had in the level ones. It just meant I had to time-share my attention more due to holding a bank angle and if I was off a bank angle, this made my rate of climb off as well as if I were off in g's. It just loaded me a little more. I noticed I became more imprecise.

Relative to the comments: Is the airplane difficult to trim? No.

Attitude control satisfactory? No, there's a tendency to oscillate in pitch attitude.

Normal acceleration a problem? No, it was not. I think that was fairly good.

A little overshoot, and consequently I picked a little bit on the heavy side - forces. But I would say I picked my forces more on the basis of picking one so that I had less tendency to disturb the airplane in pitch attitude. In other words, cut down the tendency to bobble it in pitch and what I consider to be a little heavy stick forces per g. So I think you can say one thing about here; that when I am tempted to say pilots like constant force per g, I am apparently assuming that he has good dynamics. I think with good dynamics he wants constant

stick force per g. But I can readily see from here that if he's got problems with the configuration and difficulty handling the transfer function of the airplane he's flying, he may compromise this constant stick force per g accordingly to minimize some other effect. In other words he has a fairly wide tolerance band of stick force per g and he may in one case pick heavy stick forces per g in order to minimize an oscillation tendency, and perhaps another time, he will pick a light stick force per g in order to overdrive it.

Can I hold altitude? Yep, when I fly rate of climb – only when I fly rate of climb. That's the only time I can fly it accurately. Or the other time is when I put in, cut my gain down, smooth my inputs, put in very slow inputs, and essentially act as steady state controller, then I can also control altitude.

I had much more difficulty in turns, apparently due to the fact that the g required for any particular bank angle is a function of bank angle and if I change it, that causes the rate of climb error. It also causes a proportional change between flight path angle and pitch angle and it just gets me in trouble.

Bank angle usable? Not more than 60°. 60° requires 1 incremental g which is 10° angle of attack, and above that I have speed control problems. This is one of the configurations that has a speed control problem. I haven't mentioned the speed control, but speed control is a problem.

Maintaining airspeed a problem? Yes, it is because you require lots of angle of attack in maneuvering and angle of attack produces apparently more drag required in throttle correction because you have to wait for the response time of the airspeed mode before you know whether the throttle correction that you put in was right or not. It would be interesting to put in a rate of change of airspeed control. That would be an interesting instrument, this rate of change of airspeed, so that when your airspeed was decreasing, as you went through the correct airspeed, you could just readjust your throttle quickly to make that rate of change zero for that particular g. I suggest this as a possible program for the future.

I told you about this special piloting technique and I won't discuss them again.

What instruments I using the most? Rate of climb, pitch attitude, occasionally changing angle of attack, normal acceleration. Airspeed - I probably should use more than I do but once again, if you are going 1100 knots, you're not really interested whether or not you're going 1050 or 1150.

Instruments inadequate in this configuration? Well, no. I'd like generally – the rate of climb instrument doesn't have a large enough range. I'd like a much larger range on the rate of climb so that it wasn't pegged all the time. Outside of that I'd say the instruments were all right. I wish the rate of climb was over on the pitch attitude. Those two things I'd say were inadequate. Also I'd like, as I said, an airspeed rate of change instrument.

That's all. I rate it acceptable and unsatisfactory. It's certainly controllable, but not at all a good configuration in pitch attitude control, but actually good in g control, so I have to say that it's a rating of 5 and describe it as poor. I think it's a pretty good description of it. It could even have been a 4.5, but right now I think I'll call it a 5.

PILOT C
CONFIGURATION 54, ROUGH AIR, 5 APRIL 1962

This configuration certainly is good in turbulence. I hardly had any g response. There is a disturbance which is quite noticeable, disturbance in pitch attitude which is not very easy to minimize. I'm able to control altitude quite well. It's almost as if there is low L_α here. Well, first of all, of course, it does apparently smooth the g response, very low in amplitude. But the int resting thing is that it also acts as a kind of amplifier for real short time pitch attitude changes. It blows up initial response to distrubances and makes this more evident on this pitch attitude instrument. While the disturbances may tend to be small (at this very high speed normally in terms of pitch attitude) the low L_α apparently magnifies these pitch attitudes or makes them large enough that you can see them and fly the proper control. The g response is good enough that you can go after these disturbances and smooth them properly. I would say that the turbulence went very well. I should comment a moment about the difficulties and how I am rating the configuration after turbulence.

I think that my initial ratings for turbulence are strictly on the basis of smooth air. Everything that I can see in the violent inputs, and then the rating following turbulence is essentially, I'm asking myself, is my opinion modified following the performance in rough air?

I find it difficult to increase my rating above what it is in smooth air because I know I'll always have the smooth air criticisms in the configuration. Therefore, I feel it is unrealistic to rate it an over-all rating after flying it in smooth air. Now this is a little contrary to my earlier techniques for evaluating, because first of all, it wasn't rough air versus smooth air, it was evaluating the configuration over-all in the presence of my own disturbances followed by an additional evaluation maneuver which is in the presence of disturbances other than my own (initiated by me). So there I was trying to guess what it would be like in rough air and everything else, and sometimes I guessed it incorrectly, that it would be worse in rough air or in response to external disturbances than it was. My rating may have improved slightly after having tried to fly it in the presence of external disturbances. So I stick with my rating of 5 here. I was favorably impressed with the configuration. Rough air didn't respond, the ride must be excellent. I hardly noticed any g. Then the controllability seemed to be good. I would still rate it a 5.

PILOT C
CONFIGURATION 55, SMOOTH AIR, 5 APRIL 1962

This is different. The airplane trims up OK. I didn't seem to have too much trouble with this one.

The L_α is high enough that there is pretty good correspondence between pitch attitude and flight path angle even when you're pulling g's.

I don't have near as much trouble with airspeed as I had on the last configuration; it doesn't require as much attention.

The pitch attitude response to elevator inputs starts somewhat abruptly, but not nearly as bad as the last configuration. The initial maximum variance in pitch rate is much more nearly like the steady state value, actually a little more. There's an over-shoot. Pitch attitude display in response to a step elevator input starts fairly rapidly - stops, actually reverses direction slightly - then goes on at a lower rate than the initial maximum. But the initial overshoot isn't nearly as great as the last configuration. I was sitting here trying to remember the last configuration's g response. It seems that the g response in the last configuration was much better than this - not much better, some better. By some better, I mean a little faster. It seems to me, and I can't remember the last configuration (54) that well, so maybe I shouldn't be making comparisons, but I'll tell you what I see rightly or wrongly. It seems that I have more trouble with this configuration, it's just a subtle difference, but I'm having a little more trouble with this configuration and the g response. I doesn't seem that the g's are quite as nearly in phase with my elevator inputs, consequently I have to wait apparently longer between my corrective elevator inputs and the corresponding effect on the flight path. This seems to reduce my precision of control somewhat. Now, this is not a large effect, but it seems to be there.

I guess what I'm really saying is that I would have expected this configuration to do, based on the higher L_α and better correspondence between flight path and pitch angle and the less airspeed problems, etc., a little better than it actually does.

I keep coming up with a rating of fair. I have to say that it's acceptable; so it's acceptable and satisfactory and fair. That makes it a 3. I can't make it any better than that.

It seems like I had an awful lot of trouble in picking my stick forces. I got to wondering whether I wanted - by the way I picked 100 - that's a little heavy. The problem seems to be that I want to control my g's very accurately in order to control my rate of climb. These high airspeeds, pitch attitude just isn't very good for controlling accurately rate of climb, so you end up using the rate of climb instrument and there's a delay between what you put in and the response of the rate of climb, naturally, just like there's a delay between pitch attitude and your elevator inputs. The length between the two is g acceleration. If I can resolve my g commands quite precisely and make precise changes in g, I can make predictable and precise changes in rate of climb although there will be a time delay in establishing the rate of climb. My predictor works pretty well. So I think that's why I picked the forces a little heavy, and I've been that way for a while here in these configurations. I want good g resolution and I'm afraid a little of the sacrifice of steady state forces. In other words, I get tired of holding these forces in a turn. At this airspeed, a turn will require a long, lon time. These are some of the things that arrived in my mind. A look at the open-loop response in straight and level flight certainly looks quite adequate. There's some g overshoot, a little oscillation.

Damping ratio looked like the same as the last - 35 or 40%, 35% I guess. I've already described the responses to steps and the initial overshoot in pitch rate and the attitude actually stops and reverses direction slightly and then proceeds on at a rate not grossly different from the initial pitch rate overshoot.

Altitude changes? I was a bit surprised. I had just a little bit more trouble holding them in rate of climb than I did in the last configuration in symmetrical flight. I had a little less trouble in turns.

I've gotten something from the L_{α} here but I've given up something somewhere - either I'm getting tired or else there's a change in the short period stiffness. I have a feeling that the short period is less stiff here in this configuration and that it has a lower frequency level, but I try not to measure these things because I don't want to compare them.

I do detect what appears to be a degradation in my ability to control the g's. I attribute this - it appears that it's due to the increased time lags between what I put in and what I get out in the way of g and flight path corrections.

Is the airplane difficult to trim? No.

Is attitude control satisfactory? Yes, it's pretty good. There's a little oscillatory tendency but there's good correspondence between my attitude and my flight path. I'm satisfied with it.

Is normal acceleration control a problem? No, I mean that I can sit here and wait. I can't control rate of climb as precisely as I could in level flight or in summetrical wings-level flight with the last configuration.

I've already described the factors that entered into my selection of the gear ratio.

Can I hold altitude? Yes, I can and fairly well. I have the difficulties that you would expect at this speed and that I can't use pitch attitude as the primary instrument. I have to use rate of climb but I am able to use it to fly straight and level fairly well.

Is maintaining airspeed a problem? No, it is not.

Special piloting techniques required? Nothing other than what I have described so far.

I've used rate of climb at this airspeed an awful lot. The rate of climb instrument seems to be fairly adequate except for its location. Actually, its sensitivity gets pretty low at 3000 feet or around there per minute, then it bottoms at something like 3500 feet per minute. Actually, I think it probably bottoms at a little less rate of climb or rate of descent than what it indicates here just because of this nonlinear scale. I'd like to see a rate of climb instrument that has a bigger range. I would tolerate a little reduced needle sensitivity in the lower rates of climb in order to obtain this. I'd also like to see its location over on the attitude instrument.

I'd like to make a comment here on the use of the eye movement device. I can foresee difficulty in drawing conclusions from the eye movement device. I have used my peripheral vision a fair amount here. In other words, I say I look at my attitude and try to hold the flight precisely and I'm able, for flying level flight and for small rates of climb and descent, to make corrections by monitoring the rate of climb in my peripheral vision.

As I said, I use the rate of climb. I use attitude and I find that I use g when I'm pulling g. The angle of attack, I hardly used at all. I found that I didn't have to use airspeed either because it didn't demand much attention.

Are any of the instruments inadequate for this configuration? No, they are not, aside from the comments that I've already made.

I would rate this configuration acceptable and satisfactory for what I envisioned the mission to be. However, the only fault is that I don't think they're any better than fair. I think fair probably describes them fairly well. Configuration 55 is a rating of 3.

PILOT C
CONFIGURATION 55, ROUGH AIR, 5 APRIL 1962

The flight was fairly good. The airplane certainly responded. I think that I'd be awfully

tired in 30 minutes of this - not from the large magnitudes of the g, but probably from the shaking and rattling of the airplane. As I was going through turbulence, it looked like that. I'd call it pretty good. If I see the same thing as that on a regular airplane accelerometer, I think that I'd call it moderate to severe. In other words, when you see .5 g on the accelerometer due to turbulence (not your own inputs) then that's a pretty good rattling, particularly at this sort of frequency. This configuration is quite responsive to that - to turbulence, but nowhere near as responsive as some configurations I have seen.

The ride would be moderately rough, I think. I thought that the controllability was quite good. I didn't seem to have any problems with it.

You don't try to fly the g's; you just try to minimize the pitch attitude disturbances and monitor the rate of climb and altitude to stay at approximately level flight. I found that this was relatively easy to do. I wasn't working very hard or anything like that.

The side controller characteristics I've mentioned before, and may continue to mention, are less than desirable. I find that the centering spring on the controller is objectionable and I'm supplying these small corrective inputs that are required and things like that -- minimizing these pitch disturbances. The way our controller is set up now, it seems that I don't have any centering spring due to up-elevator inputs, fairly healthy ones due to down-elevator inputs. I find this a little objectionable. Fortunately, the magnitude of inputs that were required for these maneuvers were such that I didn't even appear to have to operate in this band of centering spring forces, which was kind of good. I don't know why - I made it just as sloppy, this mechanical bobble and so forth, that it looked as if I put my inputs in without very much in the way of force, which if the centering spring is set up properly, would not necessarily be the case.

I don't know what to rate the configuration. Once again, I find that if I want to change my rating as a function of what I see in turbulence, I don't really know how much to change it because I don't have the adjectives defined adequately for flight through turbulent air. Also I don't know what my standards of comparison are. I would be tempted to rate this either a 3 or a 4. I would say that I'd be almost tempted to downgrade it slightly and that would be based 100% on the ride standpoint. In other words, this would be based on just sitting here looking at what the accelerometer is doing either while I'm controlling or while I'm not controlling it and saying that this is not the most suitable configuration for flight in turbulence. How, I know that these are mutually contradictory things. A good ride means low L_α and controllability often means a higher L_α than that which produces a good ride, so I don't really know what to do here. Also, I'm not very well calibrated on what the ride would be in flight. I don't know how often I'm liable to encounter this turbulence. I also wish to be consistent. This is hard to do if you don't have this thing very well pinned down. I've now concluded that I'd either rate it a 3 or a 3.5 but am still finding it difficult to make a choice of the two. Once again, from the controllability standpoint, it's a 3 even in turbulence. From a ride standpoint, it's probably a 3.5. I still don't know. I'll call it a 3.

PILOT C
CONFIGURATION 56, SMOOTH AIR, 4 APRIL 1962

This is a nasty configuration to fly at this true speed. The airplane I thought was fairly easy to trim, as far as its longitudinal handling characteristics go. The speed gave me considerable trouble if I used pitch attitude, because in level flight I have to fly it very precisely on the attitude indicator in order to actually be at zero rate of climb and therefore not changing altitude. Or conversely, small minute changes in pitch attitude cause relatively large changes in rate of climb. Hence your attitude instrument probably is secondary in level flight and to use rate of climb an awful lot. The fact is that I have been experimenting with this configuration using rate of climb more than I normally do and actually putting in g as a function of my error in rate of climb. And I found that surprisingly enough, I can do much better than I thought I'd be able to do. I was doing this in the climbs and descents and I found that I tend to oscillate a little bit about my desired rate of climb. I could probably hold it within probably ±100 feet/min if I close the loop pretty tightly. However, there was difficulty involved here that when I close the loop tightly on my rate of climb instrument, I am not able to track my bank angle accurately. And what happens is that my bank angle tends to change and I don't catch it right away and consequently this causes a change in my rate of climb. I have to add or take off g's. I discover that it's the bank angle that is giving me the trouble. So this is a pretty good configuration.

I should say this somewhere along here -- the short period characteristics are somewhat oscillatory and fairly fast responding.

I selected a gear ratio of 15. I think this is a pretty good compromise for this configuration. I almost picked it a little lighter, but there is a tendency to overshoot the g on more rapid pull-ups. I felt that this particular level of gear ratio gave me a better, stronger sense of what I was putting in and hence I was able to resolve my inputs better. I find that the airplane responds fast enough that I do not intentionally use step type inputs anyway very much. Smaller inputs tend to be a little step-like due to the characteristics of the controller. I like the inputs. The g was fairly closely in phase with my elevator controller inputs. Rate of changes went quite well.

The airplane is easy to fly in turns. I can hold g's accurately. I would say it is a pretty good airplane. I would estimate the damping ratio of the short period to be of the order of perhaps 35 to 40%. I am not a good judge here. That's the neighborhood. The period I did not even try to count. So we are probably slightly over 1/2 cps.

I did not seem to have too much trouble with the level turns, either the steep bank angles or the shallow ones. I had good control of rate of climb with bank angle.

There is an excellent correspondence here between my pitch attitude and my flight path angles. And so I would say this is a pretty fair configuration from controllability standpoint. I don't seem to excite the short period too much.

I didn't seem to have too much trouble with specific altitude changes.

I had trouble holding rate of climb accurately, a great deal of trouble holding it just flying pitch attitude. But when I switched over and flew the rate of climb accurately and then very tightly putting control inputs in proportional to error in rate of climb, and now this worked real well. I can control it quite accurately as I mentioned before. About level flight and in smooth air like this, this works fairly well from the standpoint that – I have to cross-check my attitude instrument to worry about my bank angle very often. However, when I was in climbing and descending turns as I mentioned earlier, I had trouble when I concentrated on my rate of climb display that I neglected my bank angle, my attitude presentation, and consequently I have a bank angle error. As a result of this, I would suggest that the location of the rate of climb instrument is inadequate. I would like to see this configuration – on other configurations flown with, I suggested flight path angle earlier on the vertical bar. Perhaps another suggestion might be just to display rate of climb on the horizontal bar. This might be very interesting to fly. It certainly would allow you to fly your rate of climb accurately while you were maintaining your attitude, your bank angle. So it would be interesting to try it. It might also be interesting if you could set in the desired rate of climb. In other words, if you want to fly level flight, you set in zero so that your horizontal bar is zero for zero rate of climb; and up or down, you take action accordingly. It might also be nice, if you are going to make a 2000 ft/min rate of climb or descent, or 5000 like you might be in a jet penetration. Of course, I don't think you'd be penetrating at this high a speed. Anyway, to be able to set in 2000 ft/min, and the bar is horizontal or zero knot. You wouldn't know that you had that rate of climb, can't fly it without that rate of climb.

Airplane difficult to trim? No, except that small pitch angle here is caused by large rates of climb and that's inherent with the speed. So it is somewhat difficult to fly level with the present instrumentation, because if you fly rate of climb too much you get off in bank angle.

Attitude control satisfactory? Very much so - the attitude control is satisfactory but the display's relatively insensitive.

Is normal acceleration a problem? No. I put sharp inputs in, there's a g overshoot, but what I find is that except for my small inputs which tend to be a little sharper, my larger inputs I put in gradually because my g stays pretty much in faith with my elevator inputs.

Can I determine what factors entered into the gear ratio choice? I've discussed that.

Can I hold altitude? Yes, fairly well. I have to close the loop pretty tightly in order to hold altitude. Well I should say that I don't have trouble. For example, I think that if you're going to fly at these speeds, you have to have a fair separation on your instrument altitudes, because if you look around the cockpit very much, you find you're off 1000 - 2000 feet and that sort of thing.

What bank angle range is usable? All bank angles.

Maintaining airspeed a problem? Absolutely none.

Is special piloting technique required? Yes, in the sense of using rate of climb and elevator inputs function in the rate of climb. That seemed to work fairly well.

What instruments did I use the most? I find that I'm using the rate of climb far more than normal. In turns, I find 60° banked turns - of course, I'm using the attitude display to get bank angle. I'm using accelerometer to hold my g's. I'm using rate of climb to determine whether I'm flying level or not. So I can make the corrections in bank angle.

Are any instruments inadequate? The location of the rate of climb appears to be inadequate and that's all so far.

I'll rate it a 2. I rated it a 2 because of the lateral-directional characteristics in force, and the other problem is this little tendency to oscillate. A little tendency to overshoot my desired g.

I'd like to comment that the rudder pedals are certainly very, very much better than they have been in the sense that the sensitivity in terms of sideslip to rudder pedal force is greatly reduced from what it has been in the other configurations that I've flown. I like this much better. I'd say it was roughly half what it was before.

PILOT C
CONFIGURATION 56, ROUGH AIR, 5 APRIL 1962

In the presence of turbulence, the g's shut the system off all the time, going definitely over 4. This is an unflyable configuration. Rating 10 in turbulence of this level.

PILOT C
CONFIGURATION 64, SMOOTH AIR, 12 APRIL 1962

I selected a gear ratio of 450 which was a compromise between a steady state stick force per g. It's a little too heavy from that standpoint. The attitude sensitivity of the pitch inputs is a little too light - well, maybe it's not too light, but it is sensitive in that regard. The compromise is flying it at 450. In straight and level flight, this is a pretty good airplane. I find that if I fly the pitch attitude and rate of climb display carefully, I can maintain level flight with surprising accuracy at this speed. I say surprising because such a tiny change in steady state pitch attitude is such a large rate of climb.

For small disturbances about level flight, the short period looks as if it's fairly stiff - a moderate stiffness. I've seen pretty high damping. The damping looks something like unity, or something like that - probably between .7 and unity. I don't detect any overshoot here. Maybe there is a fair, so it's about .7 I suppose. The short period characteristics are what I would categorize as good. In other words, the g comes on pretty quickly after I put the control inputs in.

I seem to have pretty good control of the rate of climb. I can make corrections in elevator controller based on errors in rate of climb and I can do a pretty fair job.

The initial pitch response is very sensitive in pitch attitude. If I put an elevator step in. the nose responds very abruptly. It just seems to stop and then goes on at such a tiny rate that it almost seems stopped. In other words, for a given g, the nose doesn't go very fast at this speed. Due to this low L_{α}, and this configuration does have low L_{α}, the initial response in angle of attack is large. In other words, it takes on the order of 10 - 12° angle of attack to pull 1 incremental g here. When you pull 1 incremental g or any time you put any kind of an elevator step in, the angle of attack response, which is the short period, is evident in the pitch attitude display and it's large. The thing is very sensitive initially, then the nose seems to stop and proceed on at a very, very tiny rate. The maximum pitch rate as compared to the steady pitch rate is 10 to 1 at least. I don't know what it is, but it's very large. For maneuvers about level flight, the sensitivity is a little bothersome, but I'm able to do it and get along all right.

When I start making turns, I've got a horse of a different color. I find it very easy to maintain level flight in bank angles up to 30° as long as I don't ever get off. In other words, this configuration is good about trim but if you're off trim and trying to get back on, it's a bugger.

I think that the big problem here is the pitch attitude which isn't closely related to flight path angle. You get flight path angle off your rate of climb instruments where you have to look away from your pitch attitude instruments in order to see them. I cannot see the new rate of climb out of my peripheral vision. I can't read it rather, whereas I can read the old rate of climb instrument while I'm looking directly at pitch attitude. It's a bit of a problem.

Then when I get over to 60° banks, everything goes to pot and becomes a can of worms. I got real troubles again if I'm exactly trimmed and all steadied down - this is fine and I can control it pretty well by controlling my rate of climb. This doesn't last for long because my bank angle gets off a little bit. I make a little correction in bank angle and this gives me a little tiny bit of sidelip and a little tiny bit of sideslip causes an oscillation of the rate of climb. In other words, you see the Dutch roll frequency in the rate of climb instrument in steep bank angles. While you're busy working on your rate of climb and bank angle, the g's are wrong for the bank angle and the rate of climb gets well out of hand. Your nose gets generally way down. You're going down a-hellen and it takes a loooooong time to bend that flight path back at this pseed. The only thing you can do is roll into level flight, pull some g's, and hold them. You have to gradually get your flight path back level again. This is not a very good configuration for maneuvering.

For specific altitude changes, if I'm in level flight and smooth air and I can ease the controller in and get the rate of climb up to 2000 ft/min, then I can hold it very precisely by holding the rate of climb.

Essentially, again I'm flying about trimmed flight the same way up and down. Turns get to be a little more problem because even at 30° of bank angle, I can detect the rate of climb starting to oscillate if ever I get sideslip due to making bank angle corrections. When things start to get a little off, then I start to have trouble with this configuration.

I don't think that this is an unacceptable configuration generally, but it is certainly unsatisfactory and considerably unsatisfactory for up-and-away flight in which any maneuvering was required. If you're talking about a supersonic transport going cross the country and you're flying right about a trim point, then I don't guess that this would be bad at all. I think that I could do a powerful job because the airplane does trim up well and flies well for small deviations about trim, but it's when you have to maneuver it that the handling qualities are very poor.

Is the airplane difficult to trim? No, it actually trims quite easily.

Attitude control satisfactory? Yes, for small changes about the trim point. The attitude control is also fairly good for larger maneuvering.

Normal acceleration control a problem? No, it seems to be pretty good. My flight path control is terrible in maneuvering.

Factors which entered into my selection of a gear ratio? I've already discussed these.

Can you hold altitude? I've discussed that.

What bank angle range is usable for precise flying? Not over 30°. However, you can pull 1 incremental g which requires about 10 to 12° angle of attack and hold a 60° bank angle angle with some precision although it's not very good. You can use up to 60° and I don't think you'd want to use much more than that because you get large angles of attack and you have to apply lots of power in order to hold airspeed.

Is maintaining airspeed a problem? Yes, I found that I varied my airspeed as much as ±100 knots. You have to cross-check that instrument particularly whenever you're pulling angle of attack and making a change of power. Since you don't have any reference on the instrument panel of engine power, you never know exactly how much power you should put in.

What instruments am I using most? Attitude and rate of climb. I cross-check with the accelerometer occasionally and perhaps more often with the airspeed and altimeter.

Any instruments inadequate for the configuration? No. The new rate of climb I think is a help. It isn't a cure-all for the bad handling characteristics though. It sure is a help to have some additional information once the regular rate of climb is pegged.

I think that I'll rate this configuration acceptable and unsatisfactory and fairly low in that category. I've been deciding between a 5 and a 6 ever since I've been flying it. I think poor probably describes it fairly accurately. I'd almost go to bad. I mean that if you're going to maneuver much, I'd call it bad. If you're just going to do the normal amount of maneuvering, I'd call it poor. It lies somewhere in between. I've been trying to stay away from half ratings, but I don't want to sit here and think about it all afternoon. The thing that bothers me about this configuration is that in steep bank angles, your flight path control is terrible. Yet it takes forever to get around. If you don't use steep bank angles, the rate of turn is very low. I'm unhappy every time I try to say a 5 or a 6, so I'll rate it a 5.5.

PILOT C
CONFIGURATION 65, ROUGH AIR, 12 APRIL 1962

Excellent configuration in rough air from the standpoint of ride and from the standpoint of flight path control about level flight. The turbulence had very little effect on pitch attitude. It was hardly detectable. I had good control of the rate of climb and I did keep it zero. This is a very difficult configuration to rate because about trimmed flight it's fine, but then when you fly in maneuvers it's terrible. I have to rate maneuvering flight obviously. If you were talking about supersonic transports and not about maneuvering it, or you didn't have severe requirements for holding altitudes in turns at this particular combination of speed and L_α, it'd be a pretty good configuration when you got all trimmed up. It's got good control about the trim point. I'm unwilling to revise my opinion upward. We've kind of agreed that what you see in turbulence, unless you've made an apparent mistake in your judgement of the configuration, you should not revise your opinion upward. Obviously, this opinion is not going to get worse in my opinion following rough air because it was excellent from a ride standpoint and from controllability of rate of climb about level flight. I don't think that my altitude varied more than ±30 feet. What more do you want? I'll stick with my rating of 5.5.

PILOT C
CONFIGURATION 67, SMOOTH AIR, 12 APRIL 1962

I picked a gear ratio of 25. It was selected on two things: the forces necessary to pull an incremental g and hold it for a comfortable length of time, plus the forces being able to resolve my inputs sufficiently well to be able to control rate of climb. I'd say that this is a little heavy on the stick force per g in order to get good resolution with my inputs.

The airplane does not trim up as well as the last configuration. I had more difficulty in trimming it - quite a bit more difficulty in flying about level flight. I do not have as good control of rate of climb as I had with the last. About level flight, it is certainly not as good a configuration.

The short period looks like it is less stiff and still well damped, damping ratio of 70% or so. The stiffness does look lower. There seems like there is more of a lag in the response to my inputs. The lag is not a major change, but it just seems as though it's a little lower. I find it difficult to measure the difference, but I seem to sense a difference. I notice that certainly in trying to fly rate of climb.

This configuration, as I said, is considerably worse than the last one in controlling rate of climb and not level flight. In turns, however, it's an easier configuration to control rate of climb with, although not what I'd call a good one. It's better than that last configuration (64). The lift curve slope is quite high here. As far as I'm concerned, the attitude instrument doesn't do me a whole lot of good. I'm flying my rate of climb very closely because I get rate of climb of 1000 feet to 2000 feet/min with almost undetectable changes in pitch attitude. You get to feeling that you're a bullet. In the shallow turns, I can control rate of climb fairly well. The steeper turns, I oscillate, but I can do a fair job.

This configuration I'm not too happy with. I would consider it unsatisfactory. I wouldn't consider it acceptable so that puts it in the middle category.

Is it difficult to trim? It is not easy to trim, but it is not difficult to trim either - moderate difficulty.

Attitude control satisfactory? Well, attitude control within what I can see is satisfactory.

What that is in terms of flight path, rate of climb, rate of descent and altitude changes is, I can't even detect. The change in pitch attitude, the rate of climb change is gross. I don't mean that the pitch attitude doesn't move. What I mean is that it moves mighty tiny as compared to the flight path changes we're getting in terms of rate of climb and rate of descent.

Normal acceleration control a problem? No, it is not. It seems a little bit slower responding than the last configuration that I had. It seems this way anyway. It also seems that I chase the rate of climb a little bit more.

Factors that entered into my selection of a gear ratio I've already discussed.

Can I hold altitude? Not too well anywhere. This is one of the big effects of the speed. It just puts severe requirements on your attitude. Actually, the attitude indicator isn't up to it.

Can I hold altitude straight and level? Not too well, and in turns not too well.

Bank angle range? All bank angles are usable, but I wouldn't want to fly this thing too close to the ground because I'd be afraid that I'd run into it. Bank angles that are usable are all bank angles.

Special piloting techniques? Only extreme concentration in the rate of climb in order to find out what your flight path angle is.

Instruments that I'm using most are rate of climb, altimeter, attitude indicator (mostly for bank angles, also coarse control of pitch attitude).

Any instruments inadequate for this configuration? Yes, I think the pitch angle display is really not adequate.

I find it difficult to rate the configuration. I judge myself in terms of my ability to fly a given altitude with a given degree of precision. This is not a very good configuration. I think that I have to face up to it that this is a Mach 3 configuration. What we're talking about is a supersonic transport type situation where they're going mighty, mighty fast. I think that if this is a supersonic transport, we'd have problems with the altitude separations. They're going to have to be substantial because the pilots can't fly this thing very accurately. The consequences of small error in pitch attitude are tremendous in terms of rate of climb vs. rate of descent. It takes a long time to bend the thing around a turn. I think that there will be a tendency to use steep bank angles as a result. The altitude control is not good there either. That was one of the reasons that I down-rated the last configuration. I felt that you had to use a steep bank angle in order to be able to bend the flight path with any degree of rapidity, for example, a 60° bank angle is about 1°/sec rate of turn. That means three minutes to turn it around at 60° bank angles. I think that 60° banks are a reasonable thing to be doing if any maneuvering is required. This configuration is not very good in altitude control. I have considerable difficulty in controlling altitude. I did 60° bank angles with the last configuration. My over-all summation is that this configuration is a better one for changing the flight path. For maneuvering, this is a better configuration. For altitude control during maneuvering, it's better than the other configuration but it's not very good. For flight path control, rate of climb control about level flight or trim maneuvers, it's not as good a configuration as configuration 64. I'm having to make my comparisons relative to this other configuration because the problems in flight path are rather unique to the speed. I don't remember any others to compare it to. Neither one of these are very good airplanes. One is good in one respect and poor in another, and vice versa for the other. I think that both of them are acceptable and unsatisfactory. Considering all aspects of the problem, I think that I prefer this one slightly in smooth air. I think that I'll rate if a 5. I'm not very sure whether you'll ever give me anything that's any good at this speed in terms of trying to fly precise altitude. Maybe my requirements are a little too severe. I think that what this says to us all is that we must give some strong consideration to the display requirements for a supersonic transport. The problems here are considerable. I had to evaluate this thing in terms of the display that I had. I'm debating now as to whether I'm being too severe - maybe it should be a 4.5. I don't want to penalize too bandly inherently on speed because we agreed in the beginning that it was a necessary evil. I think that I'm going to rate this a 4.5. I'm going to come up a little on it. It's somewhere between a fair and poor. The short period characteristics are fine, the L_{α} is nice and high, there's a good correspondence between pitch attitude and flight path angle. The trouble is, I can't see either one of them except

when I look at my rate of climb indicator. This is a rating of 4.5.

PILOT C
CONFIGURATION 67, ROUGH AIR, 12 APRIL 1962

Actually the altitude control is better than I expected it to be. I'd say I varied something like 70 or 80 feet which was actually better than I thought it would be. The g excursions were considerable. I grunted on several. I don't know how the dynamics of the meter affect this, but anyway, I saw some as high as 1.6 incremental. This hurts - the old back bone was beginning to hurt there. What I want to say is that this is a pretty poor airplane in rough air. It didn't respond too much. I think that it's unacceptable. It's not unflyable. I think that I might last a half-hour, but boy, I'd be a beat feller. The opinion of the configuration will go down certainly into the unacceptable category. Altitude control was good. It's something like a 7 or an 8. I don't think the word dangerous is really fit for it - bad certainly fits from the ride standpoint. I had practically no pitch angle disturbances. I found that that part was pretty good. The ride part was pretty good. I seem to be leaning toward half ratings today. I'm about ready to call it a 7.5 - I think I'll call it an 8.

PILOT C
CONFIGURATION 75, SMOOTH AIR, 13 APRIL 1962

I was happy to add 1800 knots. I was happy to see there are airplanes with satisfactory handling characteristics at this speed. Here we have one. They are not optimum nor are they excellent, but they are certainly acceptable and satisfactory. I have not decided on the rating yet, but I have been debating between a 3 and a 2.5, so you can see that it is satisfactory. Several things of interest have come up here this morning in flying this configuration (by coming up I mean they have come to my mind) – things that have been bothering me. I'll talk a little bit about them without stretching out to the usual four pages.

First of all, to run through this airplane in straight and level flight and trim. It trims fairly well.

It's very sensitive to pitch attitude of course. Small pitch attitude changes give exceedingly large rates of climb or descent.

About the small disturbances about level flight. The short period appears to be well damped and of moderate stiffness.

The response to elevator steps is initially a fairly rapid response visible in terms of pitch rate and this initially starts at a somewhat rapid rate and then slows down to something like half that value. So L_α is what I'd describe as moderate here. The L_α effects are evident in the pitch attitude response and I think that what I see here is of a desirable magnitude. In other words, the effect of L_α on my pitch attitude response here is of a desirable level. I've come to one conclusion, I think is true and fairly general, that some evidence of L_α is necessary in the pitch attitude response principally because the pilot is not overly 'rate' sensitive. Now by this I mean that if L_α has a somewhat low value, you will see in your pitch attitude response both your initial α response and your steady pitch rate response. If L_α is (and by the way, this situation is of varying degrees of goodness depending on how much of the α response you see in your pitch attitude response). So the opposite of this is when the L_α gets very, very large you don't see any response in your pitch attitude response because the change in α required to produce a given pitch rate is not detectable on the pitch attitude display. Hence you only see a steady pitch rate on your attitude display and you don't really see your α response. This means that in the ground simulator particularly, the only way you know what you're putting on in the way of g's is to look over at the accelerometer. Except I guess you could tell if they're really small and you knew exactly how fast you were going, you could tell from your pitch rate about how many g's you're getting. But this is a pretty involved process. What I'm saying is too high an L_α is bad in smooth air and so is too low an L_α. There is some optimum amount of α response that should be visible in the θ response and I don't think I was really aware of this until right now. Now the value of L_α we have here appears to be pretty good. I have seen, I guess yesterday and the day before, examples of too much α response in the θ display and too little α response in the θ display. I would say that this configuration is a good compromise. If you make L_α any lower then in steady banked turns, I lose my correspondence between θ and γ, flight path. If you make L_α any larger then I don't see my α or g response in my pitch attitude display and I don't have a good enough

feedback in that. So this seems to be a fairly good level.

At this speed though I have problems in flying level flight. We have discussed this before, I won't dwell on it now. It's just small pitch attitude changes create very large rates of climb and rates of descent. It means that it's very difficult to stay at one altitude. In the past, I have tried the different techniques for flying using rate of climb as more or less of an input to command elevator angle in order to fly level. In this particular configuration I was having enough difficulty in doing that. Then I went back and said, " By God, I'm going to fly attitude and really look closely and use the rate of climb just like I've always done as a cross-check instrument". By "always done", I mean in actual flight. That works pretty well for this configuration. It means that you don't perhaps fly quite as precisely at a given altitude when you're all trimmed up. But in other words, if you're watching the attitude display more and the rate of climb less, you detect the departure from level flight later by watching pitch attitude than if you were watching rate of climb. However, when your altitude gets off and you're trying to maneuver back on, you're able to do it more precisely and more rapidly by using the pitch attitude display even though the sensitivity is very, very low. So very definitely I am of the opinion that the solution perhaps to this sort of problem in flying at Mach 3 is to expand the pitch display - make it move further for 1° of pitch, and I might note for posterity that this particular Lear attitude indicator we have in here now has an expanded pitch display. What I'm saying is it needs an even more expanded display for Mach 3 flight.

If the heading changes the banks, the comments I've made hold here. If I fly attitude precisely, and look very carefully in order to detect the very tiny errors in pitch attitude, cross-checking with rate of climb, I can fly steep turns even with fair precision here - not the best, don't misunderstand me, it's not real good. But I can do much better than I have been able to do with these Mach 3 configurations up to now. Now in level flight and up to 30° bank angles, I tend to use probably more direct rate of climb, steep bank, in the sense, in order to put a correction in to stop a departure from level flight. But even there in the 30° banked turns, I find that flying attitude is very, very helpful. Altitude changes there are made fairly reasonably. Usable bank angles are, I think, all bank angles.

Specific altitude changes are going fairly well. I can't control rate of climb as precisely as I could with lower speed configurations, but I can do it better than I have been able to do with any other configurations at this Mach number.

I'll run through the comments. Airplane difficult to trim? No, at this Mach number, it's probably the easiest. There was one low L_α configuration I saw at this Mach number and it was awfully easy to trim about level flight. This one may not be that good, or it may be just as good. I don't think it's necessarily better.

Attitude control satisfactory? It's pretty fair for this Mach number. If I could only see my departures in attitude better, I think I could do a fairly good job.

Normal acceleration control a problem? No, I'd say it's pretty good acceleration control. I might be able to do a little bit better job if there was just a little bit less lag. Short period is well damped, probably 70%; moderate stiffness.

I might point out that the pitch attitude response to elevator steps in this configuration, even though it overshoots, is of the type that I think you want, because it's this overshoot that you see that shows you what your α response is and this is apparently quite necessary. Flight path control is pretty good for this Mach number. It's not as good as it is at lower speed.

Factors that entered in the selection of gear ratio? Control of g's, control of pitch attitude and forces to hold steady g's, like steady incremental 1. Ability to resolve small inputs, make small changes in g's and hence in small changes of pitch attitudes so as to control rate of climb. I thought for a little while after I got to evaluating the gear ratio of 125 which I selected, that maybe I picked it a little bit too sensitive and I tried 75 and it didn't improve my difficulties. I was trying to fly level in a 30° banked turn - 75 did not improve it, and it made the 60° worse. So I think 125 is a good compromise.

Can I hold altitude? For this speed, well; for considering all speeds, not too well, not so hot. Straight and level, better than in turns. Turns are a problem holding altitude and the way I figured out to do it is to go back to the old standard technique of flying pitch attitude very carefully, cross-checking with rate of climb. You have to cross-check with rate of climb because you see your Dutch roll in the rate of climb, that causes departures.

There are lags between your inputs and change in rate of climb that make it difficult to fly by rate of climb. So flying turns by pitch attitude and cross-checking rate of climb turned out to make the turn part acceptable.

What bank angle range is usable? I'd say certainly through 60°. I mean this is a good configuration in that regard. For straight and level flight, I'm not so sure that anything bigger than 60° is very useful, but it isn't in many configurations anyway.

Is maintaining airspeed a problem? No, the airspeed does vary. It requires a periodic cross-check, but it's not a bothersome thing. It does not stay constant. You must use a throttle if you want to fly it at an exactly constant airspeed, but it doesn't depart enough to really worry you. So you're content to fly at constant throttle and accept the changes in airspeed occasionally making a correction.

Special piloting technique required? No, in fact as I said, this one works best if you go back to the way you learned to fly instruments.

What instruments are you using the most? Pitch attitude, cross-checking rate of climb, cross-checking g's, altimeter, cross-checking occasionally airspeed, hardly ever even looking at the angle of attack.

Any instruments inadequate? I would say that the pitch attitude display has inadequate sensitivity. It should move more for 1° of pitch attitude.

I've got to sum it up and give it a rating. Certainly it is acceptable and satisfactory category. Only question I have is whether it is a 3 or a 2.5. I think I'll have to say that with the present display instrumentation, it will be a 3. I have problems flying it level. But basic handling characteristics appear to be fairly good. It might be a little better with a little stiffer short period as long as you could maintain this damping ratio. It certainly would be better if you improved the display. I'll rate it a 3.

PILOT C
CONFIGURATION 75, ROUGH AIR, 13 APRIL 1962

I was surprised. I thought this configuration would respond more than that. It was responding most of the time probably just due to the turbulence of the order of ±.2 g. About the most I ever saw due to turbulence was about .4 or possibly .5, I don't know. I watched for a long time, but didn't see anything over .3. So I'd say this is a pretty good configuration in rough air. I mean you're going to be bouncing around a little bit, and it's going to be somewhat objectionable. It's not going to be anywhere near like these configurations that bounce around .5, .75 g's. It's certainly nowhere near like the ones that get over 1 g, so it's significantly better than most.

The pitch attitude disturbances were negligible, I had no difficulty flying level flight. I thought it was a pretty good configuration in rough air. So my question really is whether to rate it a 3 or 3.5 in rough air. Now I have seen configurations that have responded less in terms of g's in rough air. These were configurations that had low L_α and they had generally poor maneuvering characteristics. So here's one that has to me a pretty good compromise type of configuration. In other words, the L_α is low enough that the turbulence doesn't have too strong an effect on the airplane and yet L_α is large enough that I don't have maneuvering difficulties and yet it's not too large.

So this is a pretty good compromise configuration. I hate to downrate it, but I must admit that for those g's, I would be bouncing around a little bit, and 30 minutes of it I'd find to be somewhat objectionable. Obviously if you had a gust – the best gust alleviation system is one that alleviates everything, and I don't know if such a thing is possible, but I'd like to rate it a 3 to indicate that this is a real good compromise configuration, and I'd like to rate it a 3.5 to indicate that I don't think I'd like to be bounced around this long for this much, for 30 minutes. I don't really know which to rate it. I think I'll rate it a 3. I may have been too good to it. I'm going to rate it a 3.5, just to show there are better configurations in rough air, but at this speed I haven't seen any that are better that have good handling qualities. Rating of 3.5.